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WILLIAM C. WIMSATT

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The Ontology of Complex Systems: Levels of Organization, Perspectives, and Causal Thickets¹

WILLIAM C. WIMSATT

Willard van Orman Quine once said that he had a preference for a desert ontology. This was in an earlier day when concerns with logical structure and ontological simplicity reigned supreme. Ontological genocide was practiced upon whole classes of upper-level or 'derivative' entities in the name of elegance, and we were secure in the belief that one strayed irremediably into the realm of conceptual confusion and possible error the further one got from ontic fundamentalism. In those days, one paid more attention to generic worries about possible errors (motivated by our common training in philosophical skepticism) than to actual errors derived from distancing oneself too far from the nitty-gritty details of actual theory, actual inferences from actual data, the actual conditions under which we posited and detected entities, calibrated and 'burned in' instruments, identified and rejected artifacts, debugged programs and procedures, explained the mechanisms behind regularities, judged correlations to be spurious, and in general, to the real complexities and richness of actual scientific

1 I would like to thank Irene Appelbaum, Bill Bechtel, Chuck Dyke, Stuart Glennan, Sergio Martinez, Alirio Rosales, Jeff Schank, Bob Ware, and Barbara Wimsatt for discussion and useful commentary on matters both substantial and stylistic; Sylvia Culp for very useful last minute input; and Bob Ware for his tolerance as an editor.

practice. The belief that logic and philosophy were prior to any possible science has had a number of distorting effects on the philosophy of science. One of these was that for ontology, we seemed never to be able to reject the null hypothesis: 'Don't multiply entities beyond necessity.'

But Ockham's razor (or was it Ockham's eraser?) has a curiously ambiguous form — an escape clause which can turn it into a safety razor: How do we determine what is necessary? With the right standards, one could remain an Ockhamite while recognizing a world which has the rich, multi-layered, and interdependent ontology of the tropical rain forest — that is, our world. It is tempting to believe that recognizing such a world view requires adopting lax or sloppy standards — for it has much more in it than Ockhamites traditionally would countenance. Quite to the contrary, I think that the standards for this transformation are not lax, but only different. Indeed, the standards which I urge are closer to our experience and arguably more fundamental than those used during the hegemony of foundationalist methods and values.

In the first section, I will discuss this criterion for what is real (what I call robustness): a criterion which applies most simply and directly, though not exclusively, to objects. In subsequent sections, I will use robustness and other information about our world to delineate the major structural features — primarily levels, but with some comments on what I call 'perspectives' and 'causal thickets' — which dominate our world, our theories, and the language we use to talk about both. These are higher-level ontological features, Organizational *Baupläne*, related to the things that people usually talk about under the topic of ontology (things like objects, properties, events, capacities, and propensities) as paragraphs are to words and phonemes or morphemes. But they are there nonetheless; it is only our concern with the little things, motivated by foundationalist or reductionist concerns, which has deflected our attention from them. This ontology — of levels, perspectives, and causal thickets — is no less required for a full accounting of the phenomena of the physical sciences than it is for biology and the social sciences, but its obdurate necessity has seemed more obvious in these latter cases. This may now be changing. The increased interest in fractal phenomena and chaotic and, more gener-

ally, non-linear dynamics emerging from the so-called 'exact sciences' has brought many noisy residua off the ontological scrap-heaps of the physical sciences to the center of attention as theoretically revealing data, structures, and objects with new-found status. Most of these things have never before made it into theory — or, if so, only into the 'theory of observation' under the topic of 'error analysis' where they lived in the ubiquitous error term. Messiness — or at least the right kind of messiness — is now almost a virtue in many of the sciences, as the recent explosion of interest in complexity seems to attest.² Levels, perspectives, and causal thickets are major ontological players in these complex areas — domains with significant implications for how to approach many of philosophy's most refractory problems.

Because the aim of this paper is ultimately taxonomic — to say what there is, or to describe some of the bigger things that are — the descriptive sections will essentially take the form of a list of properties, elaborated either to further explain ideas likely to be unfamiliar, or to explain relations among the properties which help to give the ideas of level and perspective their cohesiveness. Taxonomy may sound boring, but I hope to show that the description of and relations between a family of newly discovered species can be an exciting task.

2 For a philosophical response to 'the new messiness,' see for example John Dupre's provocative new book, *The Disorder of Things* (Cambridge, MA: Harvard University Press 1993). But while Dupre and I both urge major surgery on our ontologies, methodologies, and epistemological assumptions, and make movements in many of the same directions, I believe that my surgery is ultimately more conservative, particularly in defending a liberalized (and non-eliminative) descendant of classical mechanistic materialism, and is also more in accord with actual scientific practice. (Our differences on the former but I think not on the latter point may be in part ideological or rhetorical rather than substantive.) Dupre could urge in return that I haven't paid sufficient attention to the social determinants and aspects of our practice. To this I plead guilty, though I think the view argued here can both deal with and in part explain those complexities.

I Robustness and Reality

Before I say what there is in this complex world, I should give my criteria for regarding something as real or trustworthy. Particularly among those of a foundationalist persuasion, it is common to start by providing some criterion, be it indubitability, incorrigibility, or other means of picking out things or assumptions whose veracity is not open to question. One then says that that thing is real (true, indubitable, or whatever) if it is either one of these primitive things or if it is derivable from one of them via a valid inference. Only things admitted in one of these two ways are allowed. I share the foundationalist's concern with securing reliability for our conceptual structures. But I don't think that there are any criteria which both give indubitability or render error impossible, and permit any interesting inferences from that starting point. Thus I would rather give a criterion which offers relative reliability, one that you're better off using than not, indeed better off using than any other, and which seems to have a number of the right properties to build upon. Rather than opting for a global or metaphysical realism (an aim which bedevils most of the analyses of 'scientific realists'), I want criteria for what is real which are decidedly local — which are the kinds of criteria used by working scientists in deciding whether results are 'real' or 'artifactual,' trustworthy or untrustworthy, 'objective' or 'subjective' (in contexts where the latter is legitimately criticized — which is not everywhere). When this criterion is used, eliminative reductionism is seen as generally unsound, and entities at a variety of levels — as well as the levels themselves — can be recognized for the real objects they are, and foundationalism and ontic fundamentalism are in trouble. They will survive, if at all, as a local kind of problem-solving technique of significant but limited usefulness.

This criterion is what I call (following Levins) *robustness*.³ Things are robust if they are accessible (detectable, measurable, derivable,

3 See R. Levins, 'The Strategy of Model Building in Population Biology,' *American Scientist* (1966) 421-31, reprinted in E. Sober, ed., *Conceptual Issues in Evolutionary*

definable, producible, or the like) in a variety of independent ways. A related but narrower criterion has since been suggested by Ian Hacking.⁴ For his criterion (experimental manipulability via different means), Hacking draws a close link with experiment, and limits his discussions to the realism of entities. But robustness plays a similar role also in the judgment of properties, relations, and even propositions, as well as for the larger structures — levels and perspectives — I will describe below.⁵ Furthermore, the independent means of access are not limited to experimental manipulations but can range all the way from non-interventive observation or measurement to mathematical or logical derivation, with many stops in between. Experimental manipulation is just a special case. We feel more confident of objects, properties, relationships, etc. which we can detect, derive, measure, or observe in a variety of independent ways because the

Biology (Cambridge, MA: MIT Press 1984); see W. Wimsatt, 'Robustness, Reliability, and Overdetermination,' in R. Brewer and B. Collins, eds., *Scientific Inquiry and the Social Sciences* (San Francisco: Jossey-Bass 1981) for an extensive analysis and review of the concept and methodology; and for relevant case studies, see W. Wimsatt, 'Randomness and Perceived Randomness in Evolutionary Biology,' *Synthese* 43 (1980) 287-329 and 'Reductionistic Research Strategies and Their Biases in the Units of Selection Controversy,' reprinted in Sober, *Conceptual Issues*. See also D.T. Campbell, 'Pattern Matching as an Essential in Distal Knowing,' in K.R. Hammond, ed., *The Psychology of Egon Brunswik* (New York: Holt, Rinehart, and Winston 1966). Campbell's concept of 'triangulation' captures most of the ideas central to the notion of robustness; his work with Don Fiske on the 'multitrait-multimethod matrix' brought this methodology to the social sciences. See D.T. Campbell and D.W. Fiske, 'Convergent and Discriminant Validation by the Multitrait-Multimethod Matrix,' *Psychological Bulletin* 56 (1959) 81-105.

- 4 I. Hacking, *Representing and Intervening* (Cambridge: Cambridge University Press 1983)
- 5 See my 'Robustness, Reliability, and Overdetermination,' for the fullest treatment, but also my 'Complexity and Organization,' in K. Schaffner and R.S. Cohen, eds., *PSA 1972, Boston Studies in the Philosophy of Science* 20 (1974) 67-86; and 'Reductionism, Levels of Organization, and the Mind-Body Problem,' in G.G. Globus, G. Maxwell, and I. Savodnik, eds., *Consciousness and the Brain* (New York: Plenum 1976), 199-267.

chance that we could be simultaneously wrong in each of these ways declines with the number of independent checks we have.⁶ Note that the probability of failure only declines — though it can get very small, it does not go to zero. This criterion does not give certainty. Nothing does. There are no magic bullets in science — or anywhere else, for that matter. But if that's so, then certainty is not as important as generations of philosophers have supposed.

The independence of these different means of access is crucial. Independence is often not easy to demonstrate, and failures of independence are often well hidden. Cases of pseudo-robustness, while not common, are not truly rare, either, and invariably seem to involve unperceived failures of the independence assumption, or — relatedly — not sufficiently broad variation in the means of access.⁷ A more challenging case is provided by the bacterial mesosome, as discussed by Nicholas Rasmussen.⁸ This 'entity' was once thought to be a new kind of cellular organelle, but is now widely regarded as an artifact of preparation methods. Although the mesosome appeared under a variety of treatments (thus showing some robustness), they are classified as artifacts (as Rasmussen presents it) in part because crucial

6 Simple mathematical models of this and other related reliability calculations are worked out in my 'Robustness, Reliability, and Overdetermination.' If the probabilities of being correct, or of introducing error through an inference are both bounded between zero and one, then serial dependencies always reduce reliability and parallel redundancies always increase it.

7 The apparent robustness of the 'result' that group selection could not be causally efficacious is one such case, where the various supposedly independent considerations supporting this conclusion turned out not to be after all. Similarly, the once highly touted 'validity' of IQ scales is seriously compromised by the fact that agreement with older tests was used as a criterion for the inclusion of questions in newer tests, so the tests — even as composed with entirely different questions failed to be causally or probabilistically independent in the relevant sense. See my 'Reductionistic Research Strategies' and 'Robustness, Reliability, and Overdetermination.'

8 N. Rasmussen, 'Facts, Artifacts, and Mesosomes: Practising Epistemology with the Electron Microscope,' *Studies in History and Philosophy of Science* 24

properties (such as the size and number found) appeared to vary with the preparation methods in ways which were inappropriate for cellular bodies. These are ultimately failures of robustness, though mediated in part by theory: 'objects of the sort detectable through these means ought not to behave like that — therefore they are artifactual.' Culp analyzes this case in more detail, tracking the dispute longer, with additional evidence.⁹ Contra Rasmussen, she argues that lack of robustness was, as it should have been, ultimately the downfall of the mesosome. She points out that positive support for it as a natural entity stopped accumulating, while robust support for it as an artifact of preparation methods continued to increase. By the middle 1980s one had more techniques and a virtual recipe book for how to produce or avoid mesosomes, and there was very strong evidence that they were invaginations in the cytoplasmic membrane produced by preparation-induced contractions of the nucleosome; and that their production was facilitated by damage to the cytoplasmic membrane and inhibited by breaking connections between the membrane and the nucleosome which would tend to produce invaginations. The complexity of this case might suggest possible circularity for uses of robustness as a criterion for reality, but given different degrees of robustness and independence, and given specific knowledge about how different means of access may break down, and under what conditions, I think that any circularities present are not vicious.¹⁰ Indeed, if the checks or means of detection are probabilistically independent, the probability

9 Sylvia Culp, 'Defending Robustness: The Bacterial Mesosome as a Test Case' (unpublished ms)

10 See further discussion below, and see my 'Reductionistic Research Strategies' and 'Robustness, Reliability, and Overdetermination' for discussions of cases of spurious or pseudo-robustness in population biology and psychology; also see S. Culp, 'Objectivity in Experimental Inquiry: Breaking the Data-Technique Circle' (unpublished ms) for a careful and enlightening dissection of degrees of independence and interdependence among experimental techniques in molecular genetics, and contrary arguments by Rasmussen ('Facts, Artifacts, and Mesosomes') and Culp ('Defending Robustness') about the use of robustness in the analysis of an artifactual 'entity,' the mesosome, in recent cell biology.

that they could all be wrong is the product of the probabilities that each could be wrong. And this probability declines very rapidly — i.e., the reliability of correct detection increases rapidly — as the number of means of access increases, even if the individual means are not very reliable. This also gives us the requisite sense of independence needed for this criterion — namely, that the probability of failure of the different means of access should be independent. Of course, one cannot infer immediately from apparent physical independence of the means of access to their probabilistic independence in this sense. That is a further hypothesis which is sometimes false. Probabilistic independence represents a kind of mathematical idealization — a mathematical model of physical processes or, in more complex cases, of a system of interrelated physical, biological, psychological, and social processes.

Although nothing will guarantee freedom from error, robustness has the right kind of properties as a criterion for the real, and has features which naturally generate plausible results. Furthermore, it works reliably as a criterion in the face of real world complexities, where we are judging the operational goodness of the criterion, and not its goodness under idealized circumstances. We are judging its performance as well as its competence, as it were. Robustness even has the right metaphysical and epistemological properties. Thus it is part of our concept of an object that objects have a multiplicity of properties. But different properties will generally require different kinds of tests or procedures for their determination or measurement. Thus it follows that our concept of an object is a concept of something which is knowable robustly. Indeed, one of the ways in which we detect illusions is that appearances to one sensory modality are not borne out with the appropriate confirmation in the other sensory modalities — confirming, for a visual hallucination or mirage that what we see before us is not an object, not real.¹¹

Robustness can wear two faces, in a kind of epistemological figure-ground reversal which leads to a kind of almost magical appearance

11 See Campbell, 'Pattern Matching.'

of bringing yourself up by your own bootstraps. Particularly in the early stages of an investigation, we may use the agreement of different means of detection, measurement, or derivation to posit the existence of an object or of an objective property or relation which is the common cause of these various manifestations. At a certain stage, we will accept the existence of the entity or property as established — however corrigibly — and begin to use the differences observed through the diverse means of access to it as telling us still more about the object. (It is, after all, that kind of thing or property which is detectable via these diverse means, and shows itself differently through them.) We will at the same time also use these differences to tell about the means of access to the object. (This one thing or property appears in these diverse ways through these different means of access.) In this latter stage, we may compare the performance of the different means on a variety of target objects. In so doing, we are both calibrating each means against the others, and learning about their respective limitations.¹² This kind of switching back and forth can lead to considerable successive refinement both in our knowledge of the object(s) in question, and of the characteristics and limitations of the tools we have for gaining access to them.¹³ The fine tuning and power

12 Thus, in fascinating work in the late 1960s, on the interactions of visual and tactile modalities, I. Rock and C.S. Harris, 'Vision and Touch,' *Scientific American* 216 (1967) 96-104, found a complex conditional dependency in which sense we trusted when both were used. When no disparity in judgment between the two was noticed, vision was taken over touch — a judgment justified evolutionarily by the fact that we can make higher-resolution and more accurate discriminations (for shape, pattern, texture, and the like) with vision than with any of the other spatial modalities. When a disparity between the judgment of the senses is noticed, however, touch is taken over vision — again a reflection of the fact that vision is more subject to systematic distortion than touch (witness the 'bent stick' illusion). The accuracy and reliability of our different scientific instruments are related and interdigitated in ways which are at least as complex as this case, and we have to learn which to trust, under what conditions, and why.

13 A serious obstacle to both activities occurs if we cannot discover how the means of access (our instruments) work and how they can be biased or break down. In a review of work in the thirty years since the appearance of their classic and

of the refinements are increased if the objects in question turn out to form a class of diverse entities which can all be studied via the same means — as genes did for the Morgan school.¹⁴

Robustness has had a surprising history — it seems to be always there, but seldom noticed. Thus, seventeenth-century philosophers made a distinction between primary qualities (shape, extension, impenetrability, etc.) that they held were really in objects, and secondary qualities (color, taste, sound, etc.) that they held were induced in us by our interactions with the primary qualities of objects. Descartes took the primary qualities of objects as the fundamental properties of matter from which he tried to explain all else through derivation, and it was a general feature of such theories to try to explain secondary qualities in terms of primary qualities. This kind of relationship between primary and derived things became central to and emblematic of deductive and foundational approaches. The ironic fact, not noted at the time, is that the properties which Descartes and others following him chose as primary qualities were all knowable in more than one sensory modality, whereas the secondary qualities were known in just one sensory modality.¹⁵ Thus, in modern jargon, the

widely cited paper recommending a variant of this methodology in the social sciences, Donald Fiske and Donald Campbell conclude that its limited success there is due to the much greater complexity of processes affecting measurement in the human sciences, and the lack of an adequate 'theory of the instrument.' (D.M. Fiske, 'Citations do not Solve Problems,' *Psychological Bulletin* 122 [1992] 393-5.) A key part of the 'theory of the instrument' (such things as questionnaires, interviews, participant observation, and the like) must be how it interacts with the object, and this is crucial to telling whether a result is a property or product of the object, the instrument, the testing situation, or some complex relation among some or all of the above.

- 14 W. Wimsatt, 'Golden Generalities and Co-opted Anomalies: Haldane vs. Muller and the Drosophila Group on the Theory and Practice of Linkage Mapping,' in S. Sarker, ed., *Fisher, Haldane, Muller, and Wright: Founders of the Modern Mathematical Theory of Evolution* (Dordrecht: Martinus-Nijhoff 1992), 107-66
- 15 As Sergio Martinez points out in 'Robustness and Objectivity' (draft in English; Spanish version in *Dianoia* [1992]), it was also often argued that primary qualities were aggregative, which would further increase the tendency to locate the 'real'

primary qualities are robust and the secondary qualities are not. The explanatory principle of that period thus translates as this: Explain that which is not robust in terms of that which is — or, by extension, that which is less robust in terms of that which is more so.¹⁶ This is still a good principle, and one that is generally followed; it serves equally well in foundationalist and in non-foundationalist camps. It is different from, independent of, and if anything, more basic than anything else in the foundationalist methodology. Ironically then, we see that the paradigm of foundationalist approaches is simultaneously a paradigm use of robustness as a criterion for the real, and that the best applications of the deductivist paradigm occur when the foundational assumptions, objects, or properties are robust.

This indicates a common (or at least coincident) starting point for deductivist and robustness paradigms. There are other ways — elaborated in my 'Robustness, Reliability, and Overdetermination' — in which they diverge. Thus, on the deductivist paradigm, the length of derivations doesn't matter (as long as they are finite), and additional derivations of the same conclusion through different means are redundant and unnecessary. But if overall reliability is the primary concern, and one has at each stage a small but finite chance of misapplying valid inference rules, then the length of serial deductive arguments does matter. Furthermore, in a world where failure is possible, multiple derivations of a result by different paths is no longer otiose as a way of checking or providing further support. One can stray still further from foundationalist values: with parallel independent means

properties at the lowest level of aggregation — a close cousin to foundationalism. Martinez points to interesting historical connections between ideas of realism, robustness, and aggregativity. See W. Wimsatt, 'Forms of Aggregativity,' in A. Donagan, N. Perovich, and M. Wedin, eds., *Human Nature and Natural Knowledge* (Dordrecht: Reidel 1986), 259-93 and 'Emergence as non-Aggregativity,' in P.J. Taylor and J. Haila, eds., *Natural Contradictions: Perspectives on Ecology and Change* (forthcoming) for further discussion of aggregativity.

- 16 We will see examples of this below in the level-relativity of explanation, illustrated using the example of Brownian motion: between-level phenomena are always referred up or down in level for explanation.

of support available and the net reliability of the conclusion as the only concern, there is no longer any reason to limit inferences to truth-preserving ones, and the use of good inductive, abductive, or more generally, heuristic principles may have a place in the construction of exemplary arguments — in philosophy as well as elsewhere.¹⁷ Indeed, robustness as a criterion of superiority among arguments can and should cast a very broad and long epistemological shadow, once we get away from the unrealistic assumptions about human reasoning which have anchored 350 years of foundationalist thought.

I intend to apply these methodological lessons right here. Throughout this paper, I will not only be using the concept of robustness as a tool in the analysis, but I will also be employing it in the structure of the argument by using multiple concepts and arguments which individually have a heuristic character — having less than deductive analytical force. There will be lots of characterizations which represent strong tendency statements, which would be cashed out in terms of statistical rather than universal claims. These are data which can't by the nature of the objects be formulated or used in arguments which

17 I do not think this results in the demise of deductive arguments, or of philosophy, or in the fusion of philosophy and science, though there are clearly some activities which could be viewed as either or both. It does suggest a broader critique of philosophical methodologies which urge formulation of each argument in deductive form, come what may, and heaps scorn on other styles of argument, without concern for what is the appropriate argument for the context. A valid but unsound argument, or even an argument which is both valid and sound, but whose conditions of soundness are extremely restrictive, may sometimes wisely be replaced by a broader but less fragile argument, or by a number of mutually supporting though individually weaker arguments. We are similarly sometimes ill-served by the search for exceptionless laws. In both of these, we have been misled by our concerns with logic. This is not to deny that there are contexts for which deductive arguments are the tool of choice — but only to deny that they have a priority or preferability over all other tools in all contexts, or have a particular foundational significance. Robustness also gives qualitatively plausible ways of dealing with structures which contain contradictions and approximations — two features which are difficult to handle naturally with deductivist tools.

require necessary and sufficient conditions. Attempts to tighten them up would only render formulations which are too narrow in scope or fail to capture most of the interesting phenomena. It is suggestive of the situation for which 'fuzzy set theory' was invented, though the present character of that theory makes no allowance for the systematic character of biases and exceptions.¹⁸ This is a common pattern for entities, regularities, mechanisms, and explanations involving complex systems. Yet we shouldn't refuse to discuss them for that reason. They are too important for their reality to be denied, or rendered suspect by false simplifications or idealizing assumptions. We should value for that reason an analysis which recognizes the centrality they have in everyday life.

In a way, then, this analysis has something in common with folk psychology and some of the basic assumptions of ordinary language philosophy: like them, it takes for granted that the world we see, live in, respond to, and act upon, is too important, too central to our way of being, to be dismissed. But this much is not just anti-scientific sloppiness. (Ordinary language philosophers went much further.) For all of the ontological radicalism of quantum mechanics, Niels Bohr felt the need to postulate his 'correspondence principle' — that an adequacy condition for quantum theory was that it had to produce (in the right limits) the macroscopic phenomena we observe everyday. The approach advocated here proceeds more like Bohr (in spirit, if not in content), and less like ordinary language philosophy in trying to suggest the outlines of a more realistic scientifically motivated epistemology and metaphysics for approaching these problems. But before attending to the ordinary phenomenology of this new taxonomy, a bit of abstraction is necessary to see where we are going in this new philosophical landscape.

18 See Wimsatt, 'Heuristics and the Study of Human Behavior,' in D.W. Fiske and R. Shweder, eds., *Metatheory in Social Science: Pluralisms and Subjectivities* (Chicago: University of Chicago Press 1985), 293-314; and 'Golden Generalities and Co-opted Anomalies.'

Ontologically, one could take the primary working matter of the world to be causal relationships, which are connected to one another in a variety of ways — and together make up patterns of causal networks. (I won't address problems with causality in this essay. Those who favor 'Humean skepticism' will also find lots else to object to here, and can stop reading now unless they want to see how far you can get without it!) These networks should be viewed as a sort of bulk causal matter — an undifferentiated tissue of causal structures — in effect, the biochemical pathways of the world, whose topology, under some global constraints, yields interesting forms. Under some conditions, these networks are organized into larger patterns which comprise levels of organization, and under somewhat different conditions they yield the kinds of systematic slices across which I have called perspectives. Under some conditions, they are so richly connected that neither perspectives nor levels seem to capture their organization, and for this condition, I have coined the term 'causal thickets.' Much of psychology and the social sciences, for all of the appearances of local order, and local approximations to levels and perspectives, when looked at more globally and once the various idealizations of our theories are recognized, seem to be in this third state, or in a hybrid mixture which contains elements of all three. These three kinds of structures are rich in methodological and philosophical consequences for understanding the strengths and limitations of different approaches to studying problems and phenomena in systems characterized by one of them. We now turn to the first of these Organizational *Baupläne* — levels of organization.

II Levels of Organization

The analysis presented here elaborates parts of two earlier papers on reductionism and levels of organization.¹⁹ There has been a fair amount of work on levels since, in which they are taken to mean an astounding variety of things. Much of it, though relevant to the analysis of some complex systems, leads in the wrong direction for present purposes. Thus, I agree with McClamrock's argument that Marr's three 'levels' (algorithmic, computational, and hardware) are better viewed as levels of analysis or of abstraction, or as kinds of functional perspectives on a system, than as compositional levels of organization.²⁰ This conflation is apparently a common kind of mistake among philosophers of psychology.

More generally, people sometimes talk as if the material, psychological, and socio-cultural realms constitute monadic levels (e.g., as in Popper's first, second and third worlds). These rough distinctions are of major importance, delimiting, as they do, regions where different major concepts, theories, methodologies, and explanatory strategies dominate, but they are larger heterogeneous aggregates spanning multiple levels and including also other less well ordered structures, rather than single individual levels of organization. Thus, there are obviously — by any criteria — multiple compositional levels of organization within the material realm: elementary particle, atom, molecule, macro-molecule, etc., or (within the biological realm) as units of selection, for example, selfish genes (transposons), some kinds of supergenes (e.g., chromosome inversions), selfish gametes (the t-allele case in mice), selfish cells (cancer), selfish organisms, and selfish groups — all of which would fit into the material realm,

19 See Wimsatt, 'Reductionism, Levels of Organization, and the Mind-Body Problem'; and 'Reductive Explanation: A Functional Account,' *PSA 1974* (Dordrecht: Reidel 1976), reprinted in Sober, *Conceptual Issues*.

20 Ron McClamrock, 'Marr's Three Levels: A Re-Evaluation,' *Minds and Machines* 1 (1991) 185-96; D. Marr, *Vision* (Cambridge, MA: MIT Press 1982)

traditionally conceived.²¹ Similarly, most current cognitive theories recognize multiple levels of a compositional character²² within the mental realm, as any structural representation of belief or planning, linguistic structure, or hierarchical representation of features in a classification system must acknowledge. Atomic families, small groups, mobs, speakers of a local dialect, social classes, sectors of the economy, and citizens of a nation state are all obviously social, or sometimes socio-cultural units at diverse levels of organization — whose interactions follow diverse dynamics.

By level of organization, I will mean here compositional levels — hierarchical divisions of stuff (paradigmatically but not necessarily material stuff) organized by part-whole relations, in which wholes at one level function as parts at the next (and at all higher) levels, though one of the features of levels (further discussed below) is that levels are usually decomposed one level at a time, and only as needed.²³ (Thus neurons are presumably composed of parts like membranes, den-

21 For those for whom this matters, I have deliberately picked cases where the replicator is also an interactor.

22 They are represented in a compositional manner — and may be compositionally related to other mentalistic entities. This does not imply, however, that they or any mental objects would map to physical objects (as opposed to physical configurations, stable dynamical patterns, or whatever) in a successful material theory of the mind — any more than we would expect the objects of 'object-oriented programming' to do so. In fact, there is reason (suggested in part by examples like this) to believe that they wouldn't. See my 'Reductionism, Levels of Organization, and the Mind-Body Problem,' part III, for further discussion.

23 Levels are probably most frequently discussed in conjunction with accounts of hierarchical organization, of which there is an enormous literature, much of it suggestive and useful for present purposes. While many of the systems with multiple levels are hierarchical in character, I don't wish to couple levels talk to hierarchies, since I will also be interested in situations where the conditions required to define hierarchies are violated. For more on hierarchical organization, see H.H. Pattee, *Hierarchy Theory: The Challenge of Complex Systems* (New York: Braziller 1973), and for a more recent work which draws particularly broadly on the literature, see Stanley Salthe, *Evolving Hierarchical Systems: Their Structure and Representation* (New York: Columbia University Press 1985).

drites, and synapses, which are in turn made of molecules, which are in turn made of atoms, etc., down to quarks, though to the connectionist modeller, neurons are adaptive modules with properties like incoming and outgoing connections and thresholds, and which might as well be indivisible atoms for all of the use that is made of their still lower level properties.) Most of what I say below relates to material compositional hierarchies and levels, because I utilize constraints characteristic of the physical world — but this includes the physics of biological, psychological, and social objects as well.

Nonetheless, this is not a reductionistic analysis in the sense in which that term might be used by a philosopher.²⁴ Nor should it be taken as implying, either in evolutionary history, or in current 'state of the art' genetic engineering, that usually or always, the preferred, most effective, or (stepping back) that there is even always a practically possible way of making a given upper-level object by assembling a bunch of lower-level parts. This over-extension of what I have called (in 'Reductionism, Levels of Organization, and the mind-Body Problem') the 'engineering paradigm' is one of the things that have given reductionism and materialism bad names. (I remind the reader that the paradigms of genetically engineered molecules are not examples of *ab initio* constructions, but rather examples of the conversion of naturally occurring organic factories to the production of other products.) There is some assembly to be sure, but it is assembly of the jigs on the production line, and sometimes rearrangement and redirection of the line — not construction of the factory. To believe otherwise is to mistake arguments in principle for arguments in practice. (For the limitations and interpretation of such in principle claims, see my 'Reductive Explanation'). Ultimately, we sometimes just have to stop promising and deliver the goods.

24 I would urge, however, that it is reductionistic, or at least broadly mechanistic, as those terms would be understood by most scientists. See Wimsatt, 'Reductive Explanation,' or 'Reduction and Reductionism,' in Kyberg and Asquith, eds., *Current Problems in Philosophy of Science* (East Lansing, MI: Philosophy of Science Association 1979), 251-77.

One of the reasons it is important to look at material compositional levels more closely is that a number of properties of higher level systems which are treated as if they were emergent in some non-reductionistic sense follow directly from rather general properties of purely material compositional levels.²⁵ Thus (as I will show below) there is nothing intrinsically mentalistic (or social or cultural) about multiple-realizability, or the dynamical autonomy of upper level phenomena, or the anomalousness of higher level regularities relative to the lower level ones. Though each of these traits have been taken by some philosophers to be characteristic of the mental, I would argue that they are characteristic of any move from a lower compositional level to a higher one. That goes for the theory of chemical bonding relative to fundamental quantum-mechanical theories of the atom no less than for the relation between the neurophysiological [WHICH neurophysiological level?] and the cognitive [WHICH cognitive level?]. They are features which always accompany the emergence of a new stable level of organization.

As a species of reductionist, I want to get as much as I can about higher levels from the properties of lower ones. As a species of holist, it is tempting to try to do the reverse — and for evolving systems, it is not controversial to argue that the arrangement of lower-level parts (and consequently the appearance of certain higher level phenomena) is a product of higher level selection forces. And you can do both at the same time (and we do) as long as you don't commit yourself to saying that the system you study is to be exhaustively characterized by one

25 There is a significant epistemological parallel here with the research program of Stuart Kauffman's *The Origins of Order: Self-Organization and Selection in Evolution* (Oxford: Oxford University Press 1993), where Kauffman seeks to argue that many adaptive 'emergent' properties of systems emerge relatively directly as ensemble properties of classes of systems. Since they are in effect high entropy properties of such systems, we get them 'from the physics' for free, and we don't have to invoke special selective processes at higher levels to explain them. Indeed, Kauffman's research program turns out to be a particularly revealing special case of this which merits substantial further study for its methodological lessons.

approach or the other, but regard them as complementary. So it is possible to be a reductionist and a holist too — but not any kind of reductionist, or holist. Unlike an eliminative reductionist, I think that we add knowledge of both the upper level and the lower level by constructing a reduction. We *add* to the richness of reality by recognizing these linkages — we do not subtract from it. Eliminativists generally worry too much about the possibility of error at the upper level, and not enough about how stable and resilient — how robust — most upper-level phenomena are, a fact that can make the upper-level details more revealing under some conditions than the lower-level ones.

The notion of a compositional level of organization is presupposed, but left unanalyzed by virtually all extant analyses of inter-level reduction and emergence. A pioneering and important attempt to deal with levels of organization (and even more with the naturally resulting concepts of hierarchy) is Herbert Simon's classic paper, 'The Architecture of Complexity.'²⁶ This piece contains a number of useful conceptual distinctions as well as introducing a number of arguments of absolutely central importance. The views expressed here show Simon's influence strongly, but go further in other directions. I urge a view that Simon would share: that levels of organization are a deep, non-arbitrary, and extremely important feature of the ontological architecture of our natural world, and almost certainly of any world which could produce, and be inhabited or understood by, intelligent beings. (This gives levels an almost Kantian flavor.) Levels and other modes of organization cannot be taken for granted, but demand characterization and analysis. If I am right, *compositional levels of organization are the simplest general and large scale structures for the organization of matter* (see my 'Reductionism, Levels of Organization, and the Mind-Body Problem'). *They are constituted by families of entities usually of comparable size and dynamical properties, which characteristically interact primarily with one another, and which, taken together, give an apparent rough closure over a range of phenomena and regularities.* (For

26 H.A. Simon, 'The Architecture of Complexity,' reprinted in his *The Sciences of the Artificial* (Cambridge, MA: MIT Press 1981)

anyone who still believes in 'necessary and sufficient conditions' style analyses, I note at least five qualifiers in this sentence — all apparently necessary — which would be difficult at best to deal with, and the referents of these qualifiers are also often disturbingly general, and correspondingly unclear. Note also, that I said that levels are 'constituted by,' not 'defined in terms of.' Definitional language is notoriously unhelpful in contexts like these. Broad-stroke characterizations, focused with qualifications and illuminated with examples, are more useful.

Levels are in many ways the ontological analogues of conceptual schemes — though without the difficulties said (e.g., by Davidson) to attend the supposition that there is more than one of them. We live in or at one, and most of our important everyday interactions are with other entities at our level of organization — i.e., with people, tables, chairs, cars, dishes, or computers. We don't normally interact with a person's cells, or with a computer's memory chips. Persons and computers are designed to be opaque with respect to the operation of their lower-level hardware — we don't usually 'see' such hardware details unless they cause a macroscopically observable malfunction. Most of the explanations of the behavior of an entity, and most of the means for manipulating, causing, or modulating its behavior will be found and most naturally expressed in terms of entities, properties, activities, and regularities at the same level. Our level is our common world of folk psychology, or more broadly, of the objects which populate Sellars's 'manifest image' or its scientific same-level descendants.²⁷

A number of other levels are also accessible to us — in part because their effects occasionally leak up or down to our level (through those

27 Philosophical constructs like Wilfred Sellars's 'manifest image' beg to be analyzed in terms of levels of organization, though the mixture of psychological and physical properties in Sellars's construct render the analysis not straightforward, and unlike the 'folk psychology' which some writers have derived from Sellars's 'manifest image,' levels are not eliminable through conceptual revolutions. (Of course, 'folk psychology' may not be either!) See Wilfred Sellars, *Philosophy and the Scientific Image of Man* (London: Routledge 1963).

few interactions which fail to be characteristically level-bound),²⁸ and in part because we have actively searched for and exploited these few direct connections with other levels to enrich and expand our awareness of and control over these other domains of phenomena within and around us.²⁹ Because any complex material objects can be de-

28 To go up a level, a lower-level process must in effect be a deviation-amplifying process (at least under those conditions) and more generally if it is an adaptation, it must presumably be such under a suitably broad range of conditions. This suggests that a fuller exposition of this condition may require reference to the concepts of canalization and of deterministic chaos. One important way (and perhaps the only systematic way) for an event to have effects which go down in level, is through a selection process.

29 The fortuitous term 'level leakage' I owe to my former student Stuart Glennan, whose inventive and highly original work on causation and mechanism provides important further explication of both notions which support the central role that a mechanistic perspective plays in this account. See his 'Mechanisms, Models, and Causation' (PhD diss., University of Chicago 1992).

The ways in which we exploit 'level leakage' to gain access to other levels became much clearer to me through my involvement in 1979-81 (as part of a users' group) in helping to program a custom ROM module for the Hewlett-Packard HP-41C programmable calculator. The calculator was designed to be programmed in RPN (for 'Reverse Polish Notation'), a sort of assembly-level language which allowed direct manipulation of program instructions, numbers, and alphabetical characters in a controlled region of the calculator's memory, and prevented access to other regions of memory used by the calculators' system software, on the other side of a 'curtain.' A 'bug' in the definition of some of the keyboard functions on some of the early calculators gave unintended ways of creating new 'synthetic instructions' which gave ways of moving the 'curtain' and of directly manipulating the contents of control registers behind the curtain on all HP-41 calculators, whether they had that bug or not. This led to a new machine-specific discipline, called 'synthetic programming,' which gave the synthetic programmer control over many things on the HP-41 that Hewlett-Packard engineers never intended (e.g., control over individual elements in the LCD display, and individual pixels in the printer output, and the ability to do all sorts of bit manipulations to compose new kinds of instructions). 'Synthetic programming' thus gave new capabilities, and sometimes striking increases in efficiency, speed, or power. On the down side, it also gave new and dangerous ways of 'crashing' the calculator, and exploiting this new resource required much greater knowledge of the details of the machine, such as the Hexadecimal

scribed at a number of different levels of organization, identity relations must hold between descriptions of the same object at different levels. These identities provide additional important means of access to the different levels, of calibrating relations between them, and the inspirations for explanatory reductionistic mechanistic theories of the behavior of the systems in question.³⁰

code for all machine instructions, and greater knowledge of how they worked, and how they interacted with the hardware. See the 500+ page *PPC ROM Users' Manual* (The Personal Programmable Calculator Users' Group, Affiliated with Hewlett Packard 1981) for the section on the history and description of 'Synthetic Programming,' and also a later (1982) book of that same title by its main developer, William Wickes.

- 30 Identity theories are now out of fashion. Token identities seem too weak since they seem to claim nothing more than spatio-temporal coincidence, and say nothing about how the upper level phenomena are explained by the lower level characterization. And type identities seem to be subject to a myriad of possible counterexamples — both of the ordinary garden variety derived by considering how two different people with two different and presumably differently wired brains can think the same thought, and also of the more Procrustean variety preferred by philosophers — stimulated by images of the mental life of the population of China or a cerebral Martian plant, both of which are supposed to have the same functional architecture as you or I. (I find the first kind of case much more convincing and important than the two of the latter, because we have an existence proof in the first case that it is indeed possible, whereas it is not clear what if anything follows from such unconstrained 'thought experiments' as are imagined in the latter two.) These people like to talk about instantiation rather than identity. On the other hand, more scientifically motivated accounts rooted in biology such as that of Darden or Bechtel and Richardson favor talk of functional localization rather than identity. See L. Darden, *Theory Construction in Science: The Case of Genetics* (Oxford: Oxford University Press 1991); and W. Bechtel and R.C. Richardson, *Discovering Complexity: Decomposition and Localization as Scientific Research Strategies* (Princeton: Princeton University Press 1992). I am sympathetic with the latter kind of approach, but still feel the need for a kind of identity which falls somewhere in between type and token identities in its logical characteristics. What you want to know is what this (and other similar) instance(s) of this type is (are) identical with, but we are not committing ourselves to unqualified generalizations over all possible worlds which preserve the same functional equivalence classes. For a realistic account of scientific theorizing, we want a kind of context-bound type identity: not one that is

At lower levels of organization, (those of the atom and molecule) we tend to have well-defined types — of definitely specified composition and, at least in principle, an exhaustively specifiable range of possible states. At higher levels of organization (from our anthropocentric perspective — but definitely middle-range on a cosmological scale), levels become less well-defined (in terms of size scale and other properties). (See the top row of figure 1.) Higher-level types of entities may no longer have crisp compositional formulae,³¹

expected to be valid across all possible worlds, but neither one which is bound rigidly to this particular single instance. It is a contextual generalization of uncertain but not too narrow scope, where the properties of the upper level thing are explained, *ceteris paribus*, by the operation of the spatio-temporally coincident lower level causal machine. The generalization has exceptions, as do all generalizations relative to their lower-level instantiations. (Donald Davidson was too parochial in boasting about the anomalousness of the mental — it's anomalous at each level of organization, all of the way down).

- 31 It is tempting to think that this can't be true for natural kinds, but I think it is rather true that we haven't paid enough attention to the right kinds of more complex cases — and along with this (though I won't do so here) to ask more carefully what functions we want our concept of a 'natural kind' to serve. An example of the complexities I would wish to consider is provided by ecological definitions of species types — where the type of organism is defined by the ecological niche that it fills — a kind of functional equivalence. Thus there are both marsupial and placental 'squirrels' and 'dogs' — though the distance to their common ancestors are great, and the two marsupials (or the two placentals) are closer relatives by evolutionary genealogy (and DNA sequence) than the two squirrels or the two dogs. Nor will it do to say that terms 'squirrel' and 'dog' only refer to categories of folk psychology and can't be natural kinds, for these terms would enter into many regularities of behavior, and have genuine predictive and explanatory import — indeed, probably more — for most aspects of their behavior than any characterization derived from their genealogy or distances in a DNA sequence space. Finally, to say that natural kinds must have definitions in terms of intrinsic rather than functional properties would beg all of the most important questions. See also the last part of the discussion of the Brownian motion case in item 1 below for further discussion of what makes intrinsic properties important and their apparent absence for Brownian motion particles.

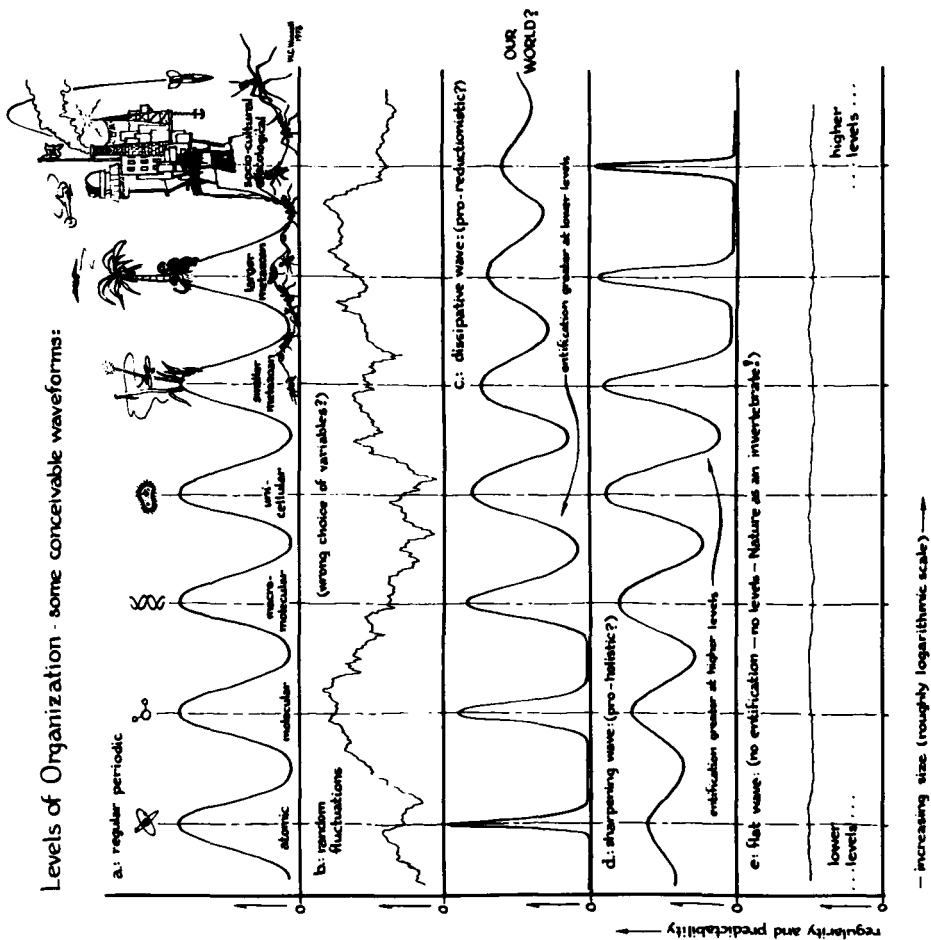




Figure 1:

Waveform Diagram for Levels of Organization. This is a representation of compositional levels of organization as they might occur in different conceivable worlds — not all of which are physically possible worlds. In each row, the vertical axis is the degree of regularity and predictability — or, in more modern terms, of pattern — for objects of different sizes. Size is represented logarithmically along the x-axis, so that regular periodic maxima would represent patterns found at geometrically increasing size scales. (Such scales would be expected if objects at each level were aggregates of roughly commensurate numbers of objects from the level immediately below.) It is argued in the text that the diagrammatic top row (a) and the second row below it (c) are the best representations of levels of organization in our world — (a) for its periodic character spilling over in an unruly fashion increasingly at higher levels, suggesting (c) for the greater diffuseness of the higher levels of organization (in the middle range of size scales which we occupy). The levels diagrammed here are really only the middle ones. One could argue that Quantum Mechanics renders the very small again diffuse, and that astronomical scales again produce well-defined objects interacting in a relatively limited number of well-defined ways. I think that it is true that (d) and (e) are NOT found in our world. As I discuss in my 'Reductionism, Levels of Organization, and the Mind-Body Problem,' a form like (d) would favor holistic over reductionistic methodologies, and non-periodic forms like (e) — where there are no levels of organization — are ruled out by Simon's arguments concerning the role of evolution via stable sub-assemblies.

but cover a range, and in some cases, composition may no longer be a primary individuating characteristic.³² They must do so for two connected reasons: (1) the disparately composed entities at a given level may nonetheless show multiple similarities in their behavior under similar conditions — all to be covered by multiple regularities (thus engendering at least rough multiple-realizability as the rule rather than the exception), and (2) these similar entities found at higher levels, despite their similarities, become occasions for an increasing number of exceptions to whatever regularities we can construct because of the increased richness of ways entities have of interacting with one another (due in part to the increasing number of degrees of freedom and of emergent properties).³³

As the richness of causal connections within and between levels increases, levels of organization shade successively into two other qualitatively different kinds of ontological structures which I have called respectively 'perspectives' ('Complexity and Organization') and 'causal thickets' ('Reductionism, Levels of Organization, and the Mind-Body Problem'). Objects whose mode of organization is characterized by these three distinct types of structures have interestingly different consequences for the methodology of sciences which study them. I will first describe some properties of levels of organization, and then say rather less about what I have called perspectives and causal thickets. These remarks are intended less as an analysis (in terms of necessary and sufficient conditions) than as a characterization of some of their most important properties, many of which are discussed further in my 'Reductionism, Levels of Organization, and the Mind-Body Problem.' The complex interplay of these various criteria and forces which mould levels of organization is one of the main things which give the complex sciences their richness and texture.

32 It obviously would not be for a functionally defined entity.

33 See Wimsatt, 'Teleology and the Logical Structure of Function Statements,' *Studies in the History and Philosophy of Science* 3 (1972) 1-80.

Levels of organization have a variety of properties which make them rich in ontological and epistemological consequences. Taken individually, these properties seem to be almost accidentally associated — important but ‘merely empirical’ or ‘contingent’ properties. Looked at more closely, their ‘merely empirical’ status is probably more a product of the fact that they haven’t yet been taken seriously by any of the dominant philosophical views. In fact, these properties of levels are closely connected in ways which make the features of levels and their analysis not just a contingent empirical matter. (For further discussion of some topics not found below — including the role of first- and third-person perspectives in an account of levels of organization and further remarks on the degree to which levels of organization are inevitable features of nature and of our conceptual scheme, see my ‘Reductionism, Levels of Organization, and the Mind-Body Problem.’) I will discuss these ‘contingent’ properties, tying them together with a network of further empirical and conceptual facts as I go.

1. Compositional levels of organization: the role of size.

a. Successive levels of organization represent a compositional hierarchy. Thus if one entity is a part of another it is characteristically at a lower level of organization than the other and lower compositional levels always pick out objects which are parts of those at higher levels. Entities at the same level of organization are usually of roughly the same size, though there tends to be greater size variance (even proportionally) at higher levels of organization, largely due to the increasing number of degrees of freedom and ways of interacting characteristic of larger systems. With the ‘engineering paradigm’ that we normally assemble complex systems out of simpler parts — a process that can be iterated — entities at successively higher levels of organization tend to show roughly geometric increases in size.³⁴

³⁴ See my ‘Reductionism, Levels of Organization, and the Mind-Body Problem.’ See also H.A. Simon, ‘The Architecture of Complexity.’

b. Size and surface/volume ratio, which is a function of size, are major factors in determining which physical forces are most central to the explanation of behavior, so the size of the characteristic objects at a level is not an accidental feature of this analysis.³⁵ Changing size is a necessary consequence of compositional hierarchies (given the old saw about how two simple objects can't occupy the same place at the same time), but changing size is also central to how different level entities get their different properties. The size scaling factor between adjacent levels is not arbitrary — if so, it would have a simpler solution. To see this, let's suppose it were arbitrary. Why not arbitrarily pick, for example, a binary aggregation scale, in which every time two similar (same-level) objects are aggregated, this involves going up a level of organization? This would surely be both possible and preferable if levels were determined by convention, or by a search for the most algorithmically economical generating relations.

Nor is it entirely without a physical basis. Binary aggregation seems natural for the architecture of computer memory, and binary doubling is naturally inherent in cell replication. In fact, starting with the same elementary particles, this scheme would produce an organizational hierarchy of all nature as regular as a giant fractal lattice. (This would be both simpler and far more elegant than what actually happens.) But, pursuing the cell-division example, this line does not produce natural vertebrae in the search for nature's joints for more than the first few cell-divisions past the zygote. Then differentiation begins, and other properties become more important, such as which cells are inside and which are on the outside of the developing cell-mass. Cell divisions in different lineages lose their synchrony fairly quickly in most metazoans. Some cell-types die and are continuously replaced by others of the same type, while others go on dividing with no significant mortality in their lineages. Consequently organisms with a large number of cells show no tendency greater than random to have their cell-numbers be at or close to integral powers of two, and the

35 See J.B.S. Haldane, 'On Being the Right Size,' reprinted in E. Nagel and S. Newman, *The World of Mathematics* (New York: Simon and Schuster 1957).

relevant functional units don't show bottom-up binary regularities, either. The basic problem with binary aggregation is that this aggregation mode does not track the regularities found in nature — the entities thus produced would seldom be those with any broad natural significance.

This idea of binary aggregation was not introduced as a serious proposal, but as an aggregative mode which is so obviously missing from the natural world — to demonstrate its absurdity as a way of indicating that the problem has a natural rather than a conventional or purely formal solution. (One might ask social constructivists why this is so!) Although size scale is an important causal determinant of levels of organization, it is not the only one, and the relevant (and highly variable) geometric scaling factor between successive levels is itself a complex function of the interplay of different physical forces on the relatively stable structures at the different levels, and the kind of system in question.

c. Size is a relevant, and in many cases a good, criterion because a number of causal interactions characteristically become significant or insignificant together for things in a certain size range. Size is thus a robust indicator for many other kinds of causal interactions.³⁶ (This should be one of the reasons why physics has so many straightforward and simple applications to aspects of our macroscopic world.) Few things could be more different than a dust particle and a bacterium — they are not *prima facie* good choices to be functional analogues for anything, but their common size and mass range nonetheless create strong similarities across whole arrays of their behavior. Thus, they both make excellent Brownian motion particles — and indeed the discoverer of Brownian motion made the plausible assumption that all such particles were alive. (After all, how else could small entities move around apparently actively in an obviously inert fluid?) Size has further consequences for the design of means of

³⁶ For a systematic discussion of the importance of size in the biological realm, see Knut Schmidt-Nielsen's fine book, *Scaling: Why is Animal Size So Important?* (Cambridge: Cambridge University Press 1984).

locomotion in bacteria which have to deal with the fact that at their size scale, it is not a trivial matter to move in ways which are not both reversible and reversed — and thus for their movements to actually take them anywhere!³⁷

d. But size is not a sufficient indicator of level — consider bacterium-sized black holes, which definitely would not exhibit Brownian motion. This is not (just) a philosopher's silly hypothetical example, though it may have been a physicist's game. There was an extended series of letters in *Nature* in 1974-75 discussing the existence and properties of black holes in the size range of 10^{-2} to 10^{-4} mm. in diameter. Cosmological debates had suggested that the creation of such microscopic black holes in the early history of the universe was a possibility. The discussion in *Nature* considered whether one of them could have caused the gigantic explosion over Tunguska in Siberia in 1908. (The standard candidate is a meteor some 40-50 meters in diameter.) Debate ceased when it was pointed out that on the 'black hole' hypothesis there should have been a comparable exit hole and explosion in the Baltic sea shortly thereafter. Such a black hole (1) would not show Brownian motion, or behave in any other way like a Brownian motion particle. (2) Things around it would respond to it in a bulk, aggregate, or an 'average' way — e.g., the rate at which it will accumulate mass and emit radiation is a function of the net disposition of mass around it, not of the detailed organization of that mass or how it is grouped into particles or chunks. (It is so much more massive than they that its trajectory and relative rate of mass accretion — over short periods of time — is also virtually independent of them and their velocities, but only depends on where its trajectory passes relative to them. However, the objects close to the black hole are dominated in their behavior by its presence — they behave to it as an individual: individual details of its motion, size, etc. do matter for them.)

37 See R. Purcell, 'Life at Low Reynolds Number,' *American Journal of Physics* 45 (1977) 3-11.

e. This case suggests a natural criterion in addition to composition for ordering entities by level of organization — probably a sufficient criterion, but alas not a necessary one.³⁸ Of two entities, if one relates to the other's properties as part of an average, but the second relates to the first as an individual, then the first is at a higher level of organization than the second. This is of somewhat broader applicability in characterizing levels than compositional relations because it enables one to order entities which are not above and below one another in the same compositional hierarchy. It indicates a kind of individuation asymmetry relating to scale which is generally true of things found at different levels in compositional hierarchies, but is not limited (as the part-whole relation is) to things in the same hierarchy. In addition, it seems plausible to say that two things which relate to one another as individuals are at the same level, and two things which relate to each other as parts of averages are both embedded in larger systems, but may vary relative to each other with respect to level.³⁹

38 This criterion is different from the compositional one, but has related presuppositions, and like any statistical property of collections, is further indirect evidence of the importance of the compositional criterion. It isn't necessary because system properties — indeed, most of the interesting ones — needn't be purely additive or aggregative functions of the properties of the parts, like an average is. The property of aggregativity — or its denial — is crucially connected with an important concept of emergence in which the higher level properties depend upon how the parts are strung together. This concept of emergence is consistent with reductionism or mechanism. (The conditions required for a system property to be an aggregate of the properties of the parts of the system — conditions on the 'composition function' relating system and parts' properties — associativity, commutativity, inter-substitutability, linearity, and invariance under decomposition and reaggregation, turn out to be very useful tools in describing the modes of organization of complex hierarchically organized systems. See my 'Forms of Aggregativity' and 'Emergence as non-Aggregativity'.)

39 There is an interesting and suggestive relation here between 'average' and 'stereotype' (an abstraction depicting an 'average' or distorted average) and level, where in this case level is broadened to include not only quasi-compositional level, but also social status or power relations. Different compositional or

*2. Levels and the simplicity of stratification:
a layered tropical ontology and the consequent
development of language strata.*

f. *Levels of organization can be thought of as local maxima of regularity and predictability in the phase space of alternative modes of organization of matter.* This is the closest I will come to a definition, because this characterization has rich connections with a number of other important properties of levels. The levels must be viewed as occupying a remapped space of reduced dimensionality relative to this enormous phase space of all physically possible states of matter, since in the levels-oriented ontology, there are strong interactions and similarities among quite diverse kinds of systems.⁴⁰ Because they are compositionally very diverse, these systems will therefore tend to be far apart in the embedding phase space, but because they are similar in terms of the variables appropriate to the levels description, they must be close together in the reduced-dimensional projection of that space in

quasi-compositional levels are involved when a member or representative of a corporation relates stereotypically to an individual — say a customer, while the individual is forced to relate to the corporation according to its individual characteristics. The differential behavior of members of different ('upper' and 'lower') classes towards one another is legendary, and the stuff of novels. If the stereotypic or stereotyped object relates to the agent as an individual, this puts that individual at a 'higher level.' If both individuals are stereotyping each other, they are just 'cogs' in their respective institutional or social 'machines,' or 'acting out their roles.' There is an oft-observed confusion between 'average' and 'stereotype' or between statistical norm and some sort of evaluative norm in common thought, but what is interesting is how this maps onto the compositional, power, or status levels distinctions.

- 40 Lest one believe that any reduction in dimensionality should lead to a simplification in the observed behavior, I suggest a visit to Edwin Abbott's classic *Flatland*, in which 2-dimensional creatures see very complex and confusing behavior of 3-dimensional objects passing through their 2-dimensional world. In fact, the predictive accuracy of a model is usually increased by increasing the dimensionality of the model — which is part of which makes levels such remarkable beasts. See also my discussion of Lewontin's 'dimensionality' argument in the units of selection controversy ('Reductionistic Research Strategies').

terms appropriate to that level.⁴¹ Almost all entities are at levels. Since most direct interactions of something at a level of organization are with other things at that same level of organization, regularities of behavior of that entity will be most economically expressed in terms of variables and properties appropriate to that level.⁴² The larger number of regularities or stable patterns involving the larger number of relatively stable entities, both concentrated at or near levels of organization, makes the characterization of levels as local maxima of regularity and predictability correct.

g. The fact that most direct interactions of something at a level of organization will be with other things at that level means that detectors of entities at a level will be or will have parts which are at the same level as the target entity, and which interact with it via properties characteristic of that level. This has several direct implications: (1) The theory of instruments for *us* to detect properties or entities at level *x* will involve causal interactions, mechanisms, objects, properties, generalizations, and regularities of level *x*. (2) If we are at a different level, this

41 Leo Buss and Walter Fontana, in 'The Arrival of the Fittest: Towards a Theory of Biological Organization' (unpublished ms), have recently been working on simulations of the evolution of life using symbolic biochemistries based upon expressions and rules of the λ -calculus — expressions which can combine and operate one another. After a time, they found the spontaneous evolution of a subset of expressions which occupied a small (i.e., lower dimensional) subspace of the space of possible λ -expressions, and whose interactions were governed by a grammar. Neither the expressions nor the rules for their interaction were built into their simulation at the start. What they have in effect done is generated the evolution of a level of organization, complete with entities and laws, in a different (and in this case, abstract) material, which has the important properties described here of a level of organization. This suggests that compositional levels of organization may in fact be an extremely general property of spontaneously evolved complex systems.

42 This suggests that ontological changes of centrally located theoretical entities at a given level should differentially affect other entities and properties at that level most strongly, and be more weakly connected with other changes at other levels. This suggests interesting constraints on theoretical changes affecting supervenience-like relations.

theory of instruments will also involve causal interactions, mechanisms, objects, properties, generalizations, and regularities at *our* level, since we need to be able to detect and record their output. For these reasons, and for others, eliminative reduction is often not possible, necessary, or desirable — our very instruments anchor us at our level, as well as at the level we are observing. Such instruments are *inter-level transducers*. (3) The entities of a level will be multiply anchored through causal interactions to other entities at that same level, and will therefore show substantial robustness at that level, and (4) many of the properties attributed to entities at a given level (or sometimes attributed to the instrument used to detect them) will in fact be disguised relational properties — properties of the interaction between target entity and instrument. (This, or something like it, should be the correct move for the classical secondary qualities, but it also occurs for many other theoretical properties — perhaps most notoriously fitness, which is a relational property of phenotype and environment, but is misleadingly attributed without qualifications to organisms, traits, and genes.) (5) Many of the apparent ontological paradoxes characteristic of different level accounts of a system — paradoxes which may appear to require the elimination of upper-level properties and entities to a zealous reductionist — arise from forgetting this relational character. (To go back to Eddington's 'two tables' paradox, there is nothing contradictory in saying that this table is both continuous, colored, and solid [when using my fingers and eyes as probes] and at the same time mostly colorless empty space [when using a beam of electrons as a probe].)

h. Theories come in levels (to analogize an observation of John Dillinger) because that's where the entities are, and simpler theories can be built with those entities (and their major interactions) than with slightly larger or smaller (or otherwise different) ones. On this account of the theorist as bank robber (or forager, or economist) theories of entities at levels provide the biggest 'bang for a buck.' These entities will be theoretically fruitful because of their many causal interactions, and the appropriate choice of entities at levels will more often produce naturally segmented systems which are nearly decomposable — which 'cut Nature at its joints' ('Reductionism, Levels of Organization, and the Mind-Body Problem'). Thus language (in which concrete nouns — entity words — are learned first) and theories constructed

using and refining this language are in this way responses to — rather than determiners of — the structure of the world.⁴³ A causal asymmetry is asserted here which runs counter to most recent linguistic or social-relativist views of the world. During the heyday of linguistic philosophy one might almost have had the impression that nature came in levels because language came in strata — a kind of theory dependence or conceptual scheme dependence of our ontology.⁴⁴ For most of the natural world, this has it exactly backwards: language is a tool for dealing with problems in the environment (including the human environment, and including the environment of different levels of organization accessed by our ever-further-reaching and multi-faceted instrumentation). For the most part, language has the macroscopic structure that it does because of the structure of the environment, and only relatively rarely is it the other way around. If most of the robust entities are at levels (as they are),⁴⁵ then the levels

43 Of course, with intentional agents, categories in theories can acquire a causal role in the generation of behavior, and if the behavior involves the production of material systems, such categories or decisions using them can result in the generation or creation of physical, biological, psychological, social, and cultural order. But in this way, theories become parts of the physical world as well as lenses through which it is viewed. The interests and needs of human agents can become materialized in similar fashion, becoming instantiated through hardware and software technology, our choice of research projects, and of how they are to be pursued, producing (in Stuart Glennan's fortuitous words) 'changes both in the lens and in the picture it presents.' In this way, the picture I urge combines elements of a constructivism in a broader-based realism. In this picture it may be extremely hard — not to mention, in most cases, pointless — to tease the aspects of construction and realism apart. Nonetheless, it is plausible to assert that theories will become more causally efficacious in that world to the extent that theoretical categories map accurately onto natural categories in the world — or onto cost-benefit approximations to them.

44 But see F. Waismann, 'Verifiability,' in A.G.N. Flew, ed., *Logic and Language* first series (London: Blackwell 1951), 117-44, for a rich and perceptive paper on levels written from the linguistic perspective, which (particularly in his accounts of the limitations of inter-level translation) makes many points I would agree with.

45 Indeed, I would argue that almost all robust entities are at levels, for reasons

will themselves be robust — they will be relatively stable and multiply detectable. Theories are tools for representing, explaining, and dealing effectively with Nature. If they deal whenever possible with objects and properties which are at levels, they will be simpler, and will deal with things that are more stable, and (for that reason) also more common and persistent.

3. *The co-evolution of levels and their entities.*

i. Richard Levins argues that organisms evolve in such a way as to minimize the uncertainty in their environments.⁴⁶ This is an important truth — but only half of the story: organisms will try (1) to be as unpredictable as possible to their predators, while (2) trying to render the behavior of resources they need, including prey, as predictable as possible! This selection for unpredictability (together with selection to respond adaptively to energetically negligible informational cues in the environment) introduces a level of predictive complexity in aspects of the detailed behavior of biological systems which seems to have no parallel in the inorganic world.⁴⁷ These kinds of interactions

given in the next section. Here as elsewhere when I use terms like 'most,' or 'almost all,' I do not assume that the entities are counted, or even countable. (They could fail to be countable to a fallibilist either by being of a non-denumerable infinity in number, or more paradoxically, by being finite, but not orderable in any compact rule-governed way, so that the only way to tell would be by doing an exhaustive survey of all cases.) In this or in most other such cases, when I say 'most,' I refer to the proportion among the cases sampled, on the assumption that they are representative — a judgment subject to the normal array of availability biases discussed by A. Tversky and D. Kahneman, 'Judgment Under Uncertainty: Heuristics and Biases,' *Science* **185** (1974) 1124-31.

46 R. Levins, *Evolution in Changing Environments* (Princeton: Princeton University Press 1968)

47 It does of course in the human realm, and for parallel reasons: counter-predictive purposive agents are the stuff of game theory, and not surprisingly, the one place game theory has found a home outside of the realm of human behavior is in evolutionary biology; for which, see John Maynard-Smith, *Game Theory and Evolution* (Cambridge: Cambridge University Press 1982).

should lead naturally to positive feedbacks, non-linear dynamics and chaotic behavior. This interdigitating web of designed predictabilities and unpredictabilities, together with the consequent selection for heightened sensory acuities probably serve more than anything else to make the regularities of the biological natural order so conditional, so context-sensitive, and so complex. It leads to the exploitation of sources of information, good predictors of fitness-relevant parameters, wherever they can be found — including at other levels of organization. Thus organisms, just like human scientists, sometimes have reasons for developing interactions which are not level-bound, and these opportunistic inter-level connections make higher level phenomena less well-defined with respect to level, and levels themselves more diffuse. The fact that these trans-level interactions can themselves sometimes be described in a systematic way which is not level-bound is ultimately what makes what I describe as ‘perspectives’ below so important for the analysis of biological systems.

j. More generally, considering Levins’s original insight, as stable foci of regularity and predictability, levels should act as attractors for other systems changing under selection pressures. These evolving systems will do so by plugging into regularities in as many levels as are accessible to them — in effect by matching levels, where possible, with their environments.⁴⁸ When they do so, then their own regularities of behavior become part of the context to which other organisms adapt. This insight is a major feature in most or all concepts of the ecological niche.⁴⁹ This point is also further generalizable:

48 Matching levels involves most obviously matching size scale and frequency dynamics parameters so that the main desiderata of the niche that the organism has chosen can be fulfilled. This will mean evolving with the behavior of the other organisms which are evolutionary factors as constraints — something which may sometimes call for matching size and frequency (most often for conspecifics), and sometimes for mis-matching one or the other or both (most often with prey or predators).

49 See T. Schoener, ‘The Ecological Niche,’ in J.M. Cherritt, ed., *Ecological Concepts: The Contribution of Ecology to an Understanding of the Natural World* (London: Blackwell 1990), 79-113, for a recent review.

k. Levels themselves evolve over time, with higher levels becoming occupied and lower levels becoming more densely occupied, while the biological objects comprising them and their interactions change on a still faster dynamics. The temporal course of levels thus mimics the ecological phenomena of succession, and the stratified and rich ontology of the tropical rain forest rather than that of a Quinean desert. This is a perspective seemingly more appropriate to modern cosmology (which is a story of the successive occupation of higher and higher of the lower 'physical' levels up through the atomic and molecular scale — and paradoxically, of lower and lower of the higher physical levels on the astronomical scale) than it is to modern ontology, but it is also profoundly evolutionary. But the level of organization is more like an ecosystem than a species — it evolves as a product of the evolutionary trajectories of the entities that compose it, and provides selection forces that guide their evolution (by affecting what is stable). From the evolutionary perspective, levels define niches for their composing entities, but these are coevolving niches which are products of the entities which make up the levels.⁵⁰

Note (as Chuck Dyke has urged upon me) that this last observation places an important constraint on the ways in which levels or their entities can be regarded as compositionally defined. In section II above I noted that while levels were compositional, this should not lead one to the mistaken view that the best way to make a higher level entity (according to the 'engineering paradigm') was to assemble it out of lower level parts. In a relevant sense, on the view advocated here, within the organic and social realms at least (I

50 Cf. the 'constructional' view of the relationship between organism and environment of R. Levins and R. Lewontin in *The Dialectical Biologist* (Cambridge, MA: Harvard University Press 1985), the concept(s) of the ecological niche (T. Schoener, 'The Ecological Niche'), and for an important and instructive extension of the concepts of niche and species to the evolution of theories and research traditions, see Douglas Allchin, 'An Ecological Model of Theory Change: The Case of Oxidative Phosphorylation' (PhD diss., University of Chicago 1991).

won't speak for large 'merely physical' aggregates), levels are for many purposes co-evolved, generated, or developed, rather than aggregated. It is still true that in a relevant sense, any higher level entity will be composed ('without remainder' — I still believe in the conservation of mass) of its lower-level parts, but it will be a (mechanically explicable) non-random generated complex of those or other lower-level parts, which may have required a diversity of 'chaperones' (as modern molecular biologists call other molecules designed to facilitate a given reaction) and other same- and higher-level co-generating complexes for its construction or development. But if this is true for many of the entities at a level, and if the entities at a level act as coevolutionary forces on one another, it is also true for the level itself, and the description of the level as a compositional entity will — to that extent — be misleading.

4. Levels, robustness, and explanation.

1. There is a general level-centered orientation of explanations which can be explained in terms of the greater stability and robustness of entities at levels of organization, and probably, more globally in terms of the consequent robustness of levels themselves. This is a general and important meta-principle for the organization of explanations which is usually taken for granted and seldom commented on. It facilitates explanatory clarity, but occasionally misfires. (See the discussion of 'perceptual focus' in the last two sections of 'Reductionistic Research Strategies,' where I discuss the biasing effect of the tendency to refer group phenomena down to the individual level of description in the units of selection controversy.) The robustness of levels tends to make them stable reference points which are relatively invariant across different perspectives and therefore natural points at which to anchor explanations of other things. Explanations of the behavior of between-level entities tend to be referred upwards or downwards in level, or both — rather than being pursued in terms of other between-level things. As we will see below, even the fine tuning of the exact 'altitude' of the between level entities we pick out — their size and thus the distance they are above the lower and below the upper levels is motivated by concerns originating at

one or the other of the bounding levels. The robustness of levels makes the level-relativity of explanations a special case of the phenomenon referred to in the preceding section — the explanation of that which is not robust in terms of that which is robust. I will consider as a somewhat extended example the case of Brownian motion. This is a between-level phenomenon which, by its very nature requires very special relations to the level below and the level above.⁵¹

A good Brownian motion particle must be small enough that sampling error effects in molecular collisions produce temporally local imbalances in change of momentum between colliding molecules and the particle — giving net random fluctuations in the motion of the particle. In effect, it is enough larger than the colliding molecules that it jiggles relatively slowly (the law of large numbers works pretty well), but not so much larger that it works ‘perfectly’ (that the jiggles are too small to detect). In a gas, the colliding molecules are moving at a mean speed equal to the speed of sound (of the order of 1100 ft./sec. in air at room temperature at sea level — so called ‘standard temperature and pressure’). The Brownian motion particle must be enough larger than the gas molecules that individual collisions do not move it too fast or far before the next collision (or actually, the next significant failure in local averaging of collisions), so that we can continue to track it visually. Increased size of a particle (relative to its molecular drivers) acts in four ways to facilitate tracking: (1) it slows down motion in response to a collision with a particle of a given momentum, and (2) the larger cross-section gives more collisions per unit time, giving temporal averaging in a shorter distance and decreases the expected absolute path length (or time) until the next perceived change in direction. (3) Increased size also decreases its relative path length (the ratio of path length to diameter), increasing the perceived relative stability

51 For a more technical exposition of some of the details, see James Jeans, *An Introduction to the Kinetic Theory of Gases* (Cambridge: Cambridge University Press 1960).

of its position and motion — an important variable in our perceptual ability to track it. (4) The Brownian motion particle also has to be large enough to reflect light in the visible spectrum, or else we couldn't see it. But — on the other side — if the particle is too large, it will not move enough for us to be able to detect the motion. I will elaborate on some of these points.

Individual jaggies in the Brownian motion particle's trajectory do not generally correspond to individual molecular collisions, but rather to local imbalances in collisions which force a distinguishable change in its velocity in times short enough to be perceived as instantaneous. Our visual system reifies paths between these super-threshold changes as straight-line trajectories, with piecewise constant velocities, but the value of that threshold is a complex function of illumination level, our static and dynamic angular resolving power, flicker-fusion frequency, and the wavelength of the reflected light — not to mention the magnification and optics of any instrumentation we use to watch it. (It is this fact which is responsible for the frequent claim that Brownian motion is a fractal phenomenon: changes in the magnification of the scene, or of the motion sensitivity characteristics of the detector will change the length scale over which velocity changes are detected.) If there are entities causing the changes in direction that we notice, as we reify these changes, they are clusters of collisions, rather than individual collisions, and the character and size of the clusters that we will reify as a group is a function of our perceptual parameters. (Other organisms could see it differently — possibly resolving a fractal pattern on a different scale determined by the relevant parameters of their visual systems.)

The colliding molecules are below the Brownian motion particle in level, and we are above it, but there are no levels in between for the Brownian motion particles to occupy. If anything is at its level, it is those clusters of molecules whose grouped collisions cause noticeable changes in velocity or direction of the particle. We do not recognize these clusters as entities for at least two reasons: (1) the perceiver-dependent and thus 'subjective' time and size scale fractal characteristics of the Brownian motion — changes in which would change the temporal boundaries of the relevant clusters, and (2) the lack of unity

of the cause of these motions — because the clusters are mere temporary assemblages which have no stability — they don't make 'good' objects.⁵² Explanations are, as here, referred downwards and upwards in level. Another revealing indicator that Brownian motion particles are between level is that they are given no intrinsic characterizations — as is indicated by the fact that things as diverse as dust motes and bacteria can all be Brownian motion particles. Between-level entities tend to be defined functionally rather than in terms of their intrinsic properties — it is almost as if they have no intrinsic properties to use in such a definition.⁵³ If so, this suggests the paradoxical conclusion that we may recognize the intrinsic properties of things, at least in part, due to characteristic interactions they have with other same-level things, since only levels have the intensity of different kinds of interactions among entities to fix unique sets of intrinsic properties as being causally relevant.⁵⁴ Multiple realizability in between-level contexts washes out the causal salience of specific intrinsic properties.

m. It is also true that in our world, the dominant methodology is reductionistic — we tend to explain features of the behavior of an entity in terms of its internal features, rather than how it relates to its

52 The still much shorter half-life of elementary particles should make it clear that the lifetime required for an object to count as a good object is level-relative. With this observation, then, we can formulate the problem more precisely as that the lifetime of the 'clusters' is not appropriate to — it is too short for — entities of that size scale. See item (n) below.

53 The converse does not follow — that anything given a functional definition is necessarily between levels. Chuck Dyke has also argued (in a personal conversation) that if we accept functional definitions of objects, there is nothing wrong with speaking of Brownian motion particles and their colliding assemblages as constituting a level. This seems to suggest either that functional definitions alone are not enough, or alternatively (perhaps suggested by the mental realm) that we need a more strongly connected set of interlocking functional definitions to be willing to reify a level on that basis alone.

54 In a recent unpublished paper, 'Time for Less Essence? Intrinsic Properties, Time-Dependent Measurement, and the Concept of Molecular Structure,' Jeffrey Ramsey has argued to a strikingly similar conclusion. His paper supports in a variety of ways the perspective urged here.

environment. This implies a kind of explanatory priority, that things not explicable at a given level are to be referred to the next lowest level, rather than to the next highest level. This is a contingent, but very deep feature of our methodological world — sufficiently so that we tend to be suspicious when we are called on to explain phenomena by going up a level (as with functional explanations), or even by staying at the same level (as with phenomenological causal theories). These suspicions are frequently unjustified, and there are situations where explanations in terms of other same-level or higher-level entities are exactly what is required. Different aspects of the reasons for and character of this bias are discussed at length in my 'Reductionism, Levels of Organization, and the Mind-Body Problem,' part III; 'Reductive Explanation'; and 'Reductionistic Research Strategies' (the section on reductionistic problem-solving heuristics and their biases) and I will not discuss them further here.

5. Time scales, multiple realizability, stability, and dynamical autonomy.

n. As noted by H.A. Simon, processes at higher levels (with a few important exceptions) tend to take place at slower rates than processes at lower levels — as measured by their 'relaxation times,' the time it takes a reaction to go a certain fraction (say one-half) of the distance to equilibrium.⁵⁵ This phenomenon would certainly follow from the fact that it takes longer for causal effects to propagate larger distances. The coupling of size and time scale might look suspiciously like an

55 The usefulness of this kind of measure depends upon the widespread scale-invariance of these fractions for different reactions over different size deviations from equilibrium — producing a recognizable exponential approach to the equilibrium state. The best known example is the 'half-life' of different radio-isotopes — the time it takes for half of their nuclei to decay, a different measurable constant for different isotopes. There are other measures (e.g., the infamous LD-50 — that dose which kills half of the relevant type of test organisms) which don't have this exponential character: two LD-50s will probably kill all or nearly all of the organisms, not 3/4 of them.

application of relativity theory to physical processes, but it is not that simple. Most causal effects propagate at speeds which are a negligible fraction of the speed of light — governed by a variety of processes which have more to do ultimately with quantum mechanics than relativity (the rate of propagation of disturbances of various energies in various solid, liquid, and gaseous media). But even if these processes are rooted in quantum mechanics, they would be so via pathways which — at least in the organic realm — are sometimes tortuously indirect. (Consider the rate of propagation of membrane depolarization pulses in nerve fibers, and locomotion speed in all types of animals — both of which increase for larger structures, but in ways that lead to decreases in the frequency of repetitive actions for larger animals. Thus, an elephant runs much faster than a mouse, while its legs move at a much lower frequency. I was astounded about fifteen years ago to discover that my expensive SLR camera did not have a lens speed fast enough to stop an ant in motion!) The net effect is to make one chary of any simplistic explanation for this probably very heterodox phenomenon.

o. The multiple-realizability of higher-level properties or types is a general fact of nature, and applies to any descriptions of entities at two different levels of organization. (It is thus entertaining to see philosophers of psychology act as if it is a special property of the mental realm.) Multiple realizability is entailed jointly by (1) the astronomically larger number of possible distinguishable micro-states than possible distinguishable macro-states — a ratio which (assuming that micro- and macro-variables have equal numbers of allowable states) grows roughly as an exponential function of the ratio of sizes of characteristic entities at the two levels and (2) the numerical identity of the upper-level system thus described with the lower-level system thus described. Given that relatively many states at the micro-level must (because of the numerical identity) map into relatively few at the macro-level, the multiple-realizability of the few by the many follows ('Robustness, Reliability, and Overdetermination').

p. More importantly, the dynamical autonomy of upper-level causal variables and causal relations — their apparent independence of exactly what happens at the micro-level — is entailed by this multiple realizability and two further facts: (3) the relative stability of

macro-level features (which persist for a characteristically longer time than micro-level features as a joint result of longer relaxation times and multiple realizability — items n and o above), in the face of (4) a constant flux of micro-level changes on a smaller size and shorter time-scale. (Items [3] and [4] can be collapsed into a single assumption by taking the relative character of the stability claim seriously.) The stability of macro-states in these conditions further entails that the vast majority of neighboring (dynamically accessible) micro-states map into the same or (more rarely) into neighboring macro-states. To suppose otherwise would require at least a tremendously convoluted and radically improbable mapping from micro-states to macro-states — if it is even consistently possible. It is dynamical autonomy, more than anything else, which makes room for higher-level causal phenomena and theories, and the causal effectiveness of macro-level manipulations.

q. Dynamical autonomy in turn entails that most (and in simple multi-level systems, an astronomical majority of) micro-level changes don't make a causal difference at the macro-level, and that, except for cases of causal divergence (such as are found widely in chaotic dynamical systems, but are still presumably relatively rare since they would be selected against in most circumstances), most macroscopically causally efficacious factors will correspond to major global and often structural differences at the micro-level. The possibility of micro-level chaos shows that most macro-systems which show stability (or the respects in which they show stability) are tuned in such a way that the micro-level changes do not cause deviation amplifying (and therefore unpredictable) changes at the macro-level in those respects. In many simpler systems (for example, the mappings between micro-states and macro-states for a gas under conditions in which it does not show turbulence) we get this easily, but it applies to more complex systems as well if the systems are to show distinguishable macroscopic order.

An example may help, and we have a particularly important one at hand, for the genetic system is a paradigmatic example of something which is systematically tuned (as a matter of design) so that small differences can have effects on a variety of size scales including the very large, in which context dependence of effects is a common phenomenon, but where it is crucial that most differences do not have

significant effects most of the time. (I suspect that most people used to inter-level relations of the sort characteristic of classical statistical mechanics [where 'law of large number' averaging is a reasonable mode of moving from one level to the next] will find the complex interplay of sensitivities and regularizing equilibrations of the relations between genotype and phenotype to be quite remarkable.)

Consider the following: We are given the genetic variability at many loci characteristic of virtually all species of organisms, and the scrambling effects of genetic recombination, so that each offspring is essentially without precedent in the specification of its genotype. Offspring of the same parents (save for identical twins) should characteristically differ at thousands to tens of thousands of loci. Furthermore, we know that small genetic changes can and often do have large effects, and that interaction between genes in producing their effects is the rule rather than the exception. Given these two facts, if we didn't know any better, it would be plausible to expect almost no correlation in phenotypic properties between different members of a species (within the range of properties defined by that species), and between parents and their offspring. Yet offspring commonly inherit their parents' traits, as well as their fitnesses — not perfectly, but much better than random. The stability of the phenotype at many levels is essential for the heritability of fitness required for the evolutionary process to work. Not only must elephants breed elephants, humans humans, and *Drosophila* *Drosophila*, but the variability and systematic and independent inheritance of individual survival-relevant characters from parents to offspring within each species must be preserved — not glued together with a thicket of epistatic and linkage interactions — if temporally and spatially local adaptation to changing environments is going to be possible. We are constantly told by geneticists of cases where a single base change in a gene or a single amino acid change in a protein has enormous consequences for adaptation and function at a variety of higher levels of organization. But this has to be the exception rather than the rule for evolution as we know it to be possible. (Sickle-cell anemia remains the classic case here, and there still aren't many cases known as yet, though these should increase with our knowledge of developmental genetics.) Nonetheless, the

plain fact remains that most genetic changes which happen under biologically normal conditions have no readily discernible effects.⁵⁶

Therefore most small micro-state changes do not make a difference at the macro level — even in systems which are characteristically sensitive to small changes. (The converse does not follow: as pointed out above, closely related or identical macro-states may be realized by widely disparate kinds of micro-states, as illustrated by the Brownian motion of dust motes and bacteria!)

r. For instantiations of stable macro-level properties, in a sense there is no micro-level explanation for why they have happened, since changes in these properties, even if characterized at the micro-level, are macroscopic in scope.⁵⁷ There is an implication, in giving extensive micro-level detail in an explanation, that the detail matters — that the event or phenomenon in question would not have happened but for the cited details, that if just one detail were different, the outcome would have been significantly different. But if a process shows multiple realizability and dynamical autonomy this is just what is denied for the relation of most microscopic events to their macroscopic descriptions. There is, however, a crucial related question — namely, why these macroscopic states, properties, and relations should be stable, and this question will require an answer which is at least partially anchored in lower level mechanisms — though not in a large number of context-sensitive micro-level details. (If selection processes are involved in the explanation, it may also require reference to events at higher levels as well.)

56 See R. Lewontin, 'Adaptation,' *Scientific American* 239 (1978); reprinted in Sober, *Conceptual Issues*, on 'quasi-independence'; and my 'Units of Selection and the Structure of the Multi-Level Genome,' in P. Asquith and R. Giere, eds., *PSA 1980* vol. 2 (East Lansing, MI: Philosophy of Science Association 1981), 122-83, for further discussion.

57 This is not quite true. I give conditions — characterized both formally and informally — under which going to the lower level is explanatory and conditions under which it is not in 'Reductive Explanation.' See especially the definition of 'effective screening off' in the appendix.

s. The operation of evolutionary and differential selection processes should tend to expand the scope of dynamical autonomy — increasing the range of multiple realizability — still further in cases where a macro-level property contributes positively to fitness. Mutations will accumulate which make its realization more likely and easier. (This is a kind of generalized ‘Baldwin effect’ response to selection.) Dynamical autonomy begins with the stability of properties of physical systems, but as the systems get larger and more complex, and their behavior more potentially variable, selection can breed stability of these usually more complex and contextual properties. Even in cases where the environment is unstable, making different properties desirable for fitness in different environmental contexts, evolution should select for context-sensitivity and conditional developmental programs — which tend to make the right things in the right contexts — all thereby increasing the heritability or stability of fitness across different environments (see my ‘Forms of Aggregativity’). The only fly in this ointment is the increasing capabilities of the predators, parasites, and competitors of each species — referred to in item (i) above, and enshrined in Van Valen’s Red Queen hypothesis — that even though each species is evolving, because of the coevolution of others, ‘you have to run as fast as you can just to stay in the same place.’⁵⁸ This should simply serve to generate increasing complexity and context-sensitivity of at least some organic interactions, something which should ultimately lead to the breakdown — through interpenetration and demodularization — of well-defined levels, and the emergence of other modes of organization in the ontology of complex systems.

One might think that one could go up indefinitely, successively aggregating and composing larger and larger systems into entities which occupy still higher levels of organization, but — whether as empirical fact, robust statistical regularity, or nomic necessity, other things emerge as salient cuts on natural processes and systems as

58 Leigh Van Valen, ‘A New Evolutionary Law,’ *Evolutionary Theory* 1 (1973) 1-30

these systems become more complex. My best guess is to think that the systems for which these other relevant modes of organization emerge are all products of biological or cultural evolution, since these are processes which will tend to produce complex, contextually conditional, systematic and characteristically adaptive behavior (see [i] above) — which has to simultaneously meet a variety of constraints at a variety of levels of organization. But in lieu of more robust arguments for this conclusion, we must beware of overgeneralizing from the cases that our theories (and our interests) have given us the greatest reasons to consider. I try in the next section to characterize the conditions leading to the breakdown of well-defined levels and the emergence of perspectives.

6. From levels to perspectives: the breakdown of levels.

As long as there are well-defined levels of organization, there are relatively unambiguous inclusion or compositional relations relating all of the things described at different levels of organization. In that case, inter-level identificatory hypotheses are an important tool of explanatory progress in localizing and elaborating lower level mechanisms which explain upper-level phenomena. There are relatively unproblematic assignments of all entities and properties with respect to level, and often systematic theories of phenomena at the respective levels. At this stage, theories are either directed to phenomena at specific levels or (for inter-level theories) acting to tie levels together by elaborating inter-level mechanisms or connections.⁵⁹ But conversely, when neat compositional relations break down, levels become less useful as ways of characterizing the organization of systems — or at least less useful if they are asked to handle the task alone. At this point, other ontological structures enter, either as additional tools, or as a replacement. These are what I have called perspectives —

⁵⁹ See N. Maull, 'Unifying Theories without Reduction' (PhD diss., University of Chicago 1976); my 'Reductive Explanation'; and L. Darden and N. Maull, 'Interfield Theories,' *Philosophy of Science* 43 (1977) 44-64.

intriguingly quasi-subjective (or at least observer, technique or technology-relative) cuts on the phenomena characteristic of a system, which needn't be bound to given levels. Since my discussions of perspectives in 'Complexity and Organization,' and of the relation of levels, perspective and causal thickets in 'Reductionism, Levels of Organization, and the Mind-Body Problem,' an even broader diversity of different perspective-like things have appeared in the literature of the last nineteen years, and have been invoked to solve a similarly broad range of problems. This characterization of perspectives is tentative, incomplete — and still unsettled even on such major questions as whether they are a unitary kind of thing. Nonetheless, there is a class of such things which do have a lot in common. I will provide a tentative list of properties of these strange objects, and a set of examples suggesting some of their differences as well as their similarities. Further refinements will have to await another occasion.

The transitions suggested here — from levels to perspectives to causal thickets characterize systems in terms of increasing complexity and context-dependence, and lower modularity and degree of regularity. This is an ordering in terms of kinds of complexity. It is not a natural evolutionary trajectory for systems, or any other kind of natural dynamical transition. Although, if I am right, systems later in this sequence first appear after systems earlier in the sequence (as a result of the continuing action of biological and socio-cultural evolutionary and developmental processes), there are specifiable circumstances in which selection processes favor simplicity, modularity, near-decomposability, increased regularities of behavior, and well-defined compositional relations. Thus, with few exceptions, the order given here should be regarded as taxonomic, rather than temporal. Given the taxonomy, we may later wish to argue about temporal trends.

t. As higher levels get more complex (they have more degrees of freedom), they get more diffuse, and they overlap more in size scale and other related properties with neighboring levels, and engender perspectives and thickets. With more molar properties at the higher levels, and each one a potential pathway for causal interaction with entities which have or respond to that property, there are more ways to 'plug into' a level. With more degrees of

freedom, higher-level objects get potentially richer in their budget of properties, more multi-dimensional. At their best, they should thus be capable of higher degrees of robustness than lower-level entities. (There should be more ways of interacting with a spouse than with a quark!) There should also be more ways of being not very robust — of being only marginally connected to the causal processes of a level, and also more ways in which objects could interact simultaneously with or bridge two or more neighboring levels. These last two kinds of cases would increase the diffuseness of the levels associated with the entities. Thus as levels get higher and more complex (up, roughly through the level of the ecological community or ecosystem, and perhaps on up to the biosphere), we should expect them to get more diffuse, for levels to overlap more, and for it to get more difficult to localize an entity or phenomenon by level unambiguously and for all contexts. (See figure 1.)⁶⁰

u. As objects find new ways to bridge levels, fluctuations at the lower level which — without the bridge — average out at the upper level, are now transmitted directly, (as we can observe Brownian motion with the aid of a microscope, and through that, the effects of micro-level events) generating the possibility of macro-level amplification of these micro-level events, creating a kind of sensitive dependence on initial conditions which will tend to increase the number of circumstances under which macro-level regularities will break down. Thus we should expect that the maximum degree of regularity of

60 At still higher (e.g. planetary, solar, or cosmological) levels, this process seems to be reversed, for several complex reasons: many of the still higher level processes are driven by bulk or average processes at lower levels and thus tend to produce regular behavior, but some represent divergent processes producing chaotic irregularities whose effects we cannot characterize except in terms of fractal, and thus scale-independent patterns. Perhaps the absence of differential selection processes and predator-prey and parasitism networks, which ferret out any usable order while simultaneously generating designed unpredictabilities (h above) allows a less complicated dynamics, or perhaps it is equally or even more complicated, and we simply do not have yet the motivations to understand it or the tools to see it.

upper-level phenomena for complex organized systems would be less than that for simpler systems composed of more homogeneous parts. This is the complement to the 'diffusion' of levels: as they come to span a broader range of sizes, the maximum predictability decreases, almost as if the area under the level waveform for each level is a constant.⁶¹ (See figure 1c.) One must remember that small differences — fluctuations or signals — make a difference when they are detected by a system designed to respond to them, and for which the pattern is significant. The human eye can detect a single photon — a micro-level event to be sure, but not yet a pattern. The number of photons, if appropriately distributed in space and time, necessary to convey information is larger than this (probably of the order of 10), but still astoundingly small.⁶² Detectable information can lead to macroscopically major (and, with modern technology, even further divergent) behavior.

v. At the same time, we should also expect (ultimately, for reasons of increased dimensionality) to find more frequent, obvious, and severe context-dependence of the behavior of our entities at higher levels of organization. This would most often be expressed via systematic and not so systematic exceptions to simple generalizations involving these entities. This is one of the reasons why it is better to think of regularities in complex systems in terms of mechanisms rather than laws — the latter, but not the former suggests a search for exceptionless generalities and explanatory completeness, whereas the former fit naturally into a scheme which is satisfied by providing a characteristic *ceteris paribus* qualified articulation of causal factors (see my 'Reductive Explanation').

w. Finally, as it becomes more common for entities to interact directly with other entities only through a subset of the properties which are causally relevant at that level, with different entities re-

61 This is a qualitative remark. There is of course no reason to suppose that there should be this kind of relation.

62 Hugh R. Wilson, personal conversation.

sponding to different subsets, the notion of a niche⁶³ becomes more relevant to the characterization of their behavior. This notion of a niche makes it clear and naturally explicable how different systems could act upon and react to the 'same' environment in fundamentally different ways. The fact that the niche must be characterized relative to the organism — it is mutually defined by the organism and its 'objective' environment (the configuration of physical and biotic factors affecting its evolution) — introduces a feature of subjectivity which we will explore further below.

III Perspectives: A Preliminary Characterization

What I am calling perspectives is probably a diverse category of things which nonetheless appear to have at least some of the properties of being 'from a point of view' or to have a subjective or quasi-subjective character. In spite of that, they differ substantially in terms of their other properties, and in terms of their relative 'objectivity.' Their 'subjective' character is because of the following further properties which they share. (The parenthetical remarks are usually further elaborations of how this is so.)

(1) Perspectives involve a set of variables which are used to characterize systems or to partition objects into parts, which together give a systematic account of a domain of phenomena, and which are peculiarly salient to an observer or class of observers because of the characteristic ways in which those observers interact causally with the system or systems in question. (So far, this does not distinguish a perspective either from a methodological approach, or from the ecological niche of a species — two things which both have a kind of observer-relativity, and also have the curious objective-subjective duality I think characterizes a broad range of what I wish to call perspectives.)

63 Derived originally from ecology. Cf. Schoener, and also Allchin.

(2) The set of variables in question is recognized not to give a complete description of all aspects of the systems which they are used to investigate. Thus in the relevant sense, there is an explicit denial of a closure clause. (If this is viewed as capturing an important aspect of subjectivity — which I think it does, it is the recognition that it makes no sense to speak of something as subjective [or as objective] without the other category — which at this stage [from the subjective side] involves at least the recognition that there is something outside of the boundary of the subjective.)

(3) In spite of this, there may be a restricted closure of the following sort: there is a reasonably well-defined class of problems which can be solved without bringing in information from outside the perspective. These are treated as paradigmatic problems for that perspective. These may also be problems which cannot (or cannot plausibly) be solved in any other way. Thus there are paradigmatic anatomical, physiological, and genetic problems, though (cf. [2] above), no one believes that these approaches individually exhaust what may be said about the organism. (This suggests a kind of unity and systematic problem-solving utility to the subjective. There are things one can accomplish wholly within the subjective perspective, and things that can be plausibly only solved from within the subjective — or a particular subjective — perspective.) In effect, this says that perspectives partition problem-space in a nearly-decomposable fashion.

Indeed (4), it is commonly taken for granted that multiple perspectives can be applied to different aspects of the behavior of a system. (Without this, I think that there is not yet a recognition of the objective — it is a recognition of the robustness of the system accessed by the different perspectives.) I will deliberately refrain at this stage from saying that the objective requires the existence of other subjectivities — and thus could perhaps be characterized as the inter-subjectively accessible, or interpersonally robust, or merely the applicability of other perspectives, which could still be true in a Robinson Crusoe universe with plenty of external robust objects but no other persons.

I won't here say anything more about the personal, interpersonal, and material realms, but to note that robustness, levels, and the idea of a perspective, together with an account of what it is to have a shared perspective are useful tools in characterizing our objective, mental

and social worlds. (In the last section of 'Reductionism, Levels of Organization, and the Mind-Body Problem' I note and exploit parallels between the kinds of access we have to things at our own level and the less direct access we have to things at other levels, and the dichotomy between first-person and third-person perspectives.) But that is for another time and place. I want here to talk particularly about the kinds of complexities which make levels break down. The next two properties of perspectives are described more fully in my 'Complexity and Organization' and 'Reductionism, Levels of Organization, and the Mind-Body Problem.'

(5) Simple systems as well as complex ones can be described from a variety of perspectives, but will differ in the degree to which they have problems which are trans-perspectival — which require the use of information from more than one perspective for their solution. Simpler problems are bounded and solvable with the resources of a single perspective. Simpler systems have more of their problems (or more of their problems for the purposes at hand) bounded within individual perspectives. Note that since problems usually arise out of purposes, a system can be simple for some purposes, and complex for others.

(6) The complexity of trans-perspectival problems also varies from simpler to more complex with whether they decompose systems in ways which (1) are spatially coincident (in which case the different perspectives must also be either at the same level, or span the same range of levels) (2) are hierarchically rationalizable relative to one another, so that the parts of one perspective are all whole systems in another, (in which case the perspectives are related to one another as different level descriptions of the same system) or (3) overlap in arbitrary ways. The last case produces an enormous increase in complexity, but is common in the biological, psychological, and social worlds.⁶⁴

⁶⁴ This is called 'descriptive complexity' in my 'Complexity and Organization,' and the preceding kind of complexity is called 'interactional complexity.'

(7) Note that levels come out as a kind of special case of perspectives on this analysis — a class of perspectives which map compositionally to one another so that their entities are related without cross-cutting overlaps in a hierarchical manner. It is tempting to say that we need to require also that the entities/parts at levels are especially robust, though that may come out for free given that hierarchical (and modular) compositionality will tend to require or entail substantial robustness of the systems and parts at all levels. Note that thus far, I have introduced nothing that a hard core materialist could not accept. (Indeed, I believe that all that I have introduced so far a hard-core materialist must accept.) Given this, hierarchical compositionality suggests a number of further interesting (but at this time still speculative) connections: (1) The ‘nearly sealed’ aspect of living at a level of organization (the fact that level-leakage is relatively rare), and the comparatively torturous and indirect paths to systematic access to another level can at least help to explain qualitatively the first-person/third-person dichotomy between subjective and objective modes of access indicated in my ‘Reductionism, Levels of Organization, and the Mond-Body Problem’; and through that (2) it may suggest naturally how subjectivities can be seen to be anchored in a natural world. (3) Also, if ‘level leakage’ is just a variety of ‘perspectival leakage,’ it suggests that and how modest amounts of comparability or ‘leakage’ between subjectivities may be essential both to the recognition of other subjectivities and the reality anchoring of our own (necessitated by the private language argument). It also predicts (4) that, how, and why the breakdown of levels with increasing complexity can come to create problems for the localization and bounding of subjectivities as well as for the bounding of well-defined perspectives. This latter problem I take to be connected to new wave contextual theories of consciousness.

I now wish to change the subject again, and to consider perspectives which are not levels. They may fail to be levels either because they are too small — they are located mostly at levels, but aren’t of sufficiently broad span to count as levels. Or they may fail to be levels because, in a way, they are too big — or rather they cross-cut levels: they are transverse sections which do not include more than a small fraction of the phenomena at any given level, but span phenomena at more

than one (usually at several) levels. It is these two basic kinds of entities which allow us to go beyond levels to importantly different kinds of entities.

(8) The smaller variety of perspectives are those things which look most subjective, since they are most explicitly keyed to the 'point of view' of a particular kind of organism or observer. When objectively characterized without regard to other than physical or biological properties, I will call these niches, because I think that the ecological niche of a biological species is the prime exemplar of this.⁶⁵ When characterized explicitly cognitively and subjectively, with respect to the cognitive and sensory capacities for and from the point of view of an animal, I will call this the subjective niche, or *Umwelt*, to use von Üxkull's term.⁶⁶ This notion of perspective naturally suggests further subdivisions which are psychological or cultural rather than biological in character, and how to make these further subdivisions (and how many to make) is an important question which I will raise, but not address further here. Is there a paranoid schizophrenic's perspective? One or many? Is there a female perspective? is it cultural or biological? is there a feminist one? an upstate-New Yorker's or a Manhattanite's perspective? an only child's (first child's, second child's...) perspective? Does each new interest group or reference group individuate a perspective or a component of a perspective? Does every person? Does every life stage? How has my perspective changed since I was an assistant professor? Got married? Become a father? Learned how to program in Pascal? Even we must follow Quine here in recognizing that there may be too many potential perspectives standing in the

65 This is perhaps just a first approximation: I am unhappy with the implicit claim that ecological niches are confined to a single level. See item (i) above. Whether 'predominately to a single level' would do is another question; cf. Schoener.

66 Jacob von Üxkull, 'A Stroll Through the Worlds of Animals and Men: A Picture Book of Invisible Worlds,' in Claire H. Schiller, ed., *Instinctive Behavior: The Development of a Modern Concept* (New York: International Universities Press 1957), 5-80; and T. Nagel, 'On What It's Like to be a Bat,' *The Philosophical Review* 83 (1974) 435-50, are the best (and remarkably close) exemplars of this position.

doorway! So how should we decide? Fred Lighthall is exploring this domain and it is the topography of many of the most important battles in the social sciences.⁶⁷

(9) What I called perspectives in my 1974 paper 'Complexity and Organization' is not usefully captured by any of these. It is the 'larger' variety of perspectives promised above. It is a more robust ontological category than they are, since it is not essentially defined by the relationship of a single kind of entity with its environment. Perspectives in that paper (1) spanned more than one level, and thus could not be ordered as higher and lower or more primary and secondary than one another, (2) gave criteria for decomposing systems into parts using the properties and tools appropriate to that perspective, (3) were manifestly incomplete descriptions of their objects, (4) were such that different perspectives (for complex systems) could cut up systems in quite different ways which were not easily comparable to one another, (5) had a class of problems that they could solve in isolation, and (6) (for complex systems) other problems which could not be solved without bringing in the resources of another perspective or perspectives.

Anatomy, physiology, and genetics are different perspectives on an organism in this sense. Perspectives may sometimes correspond loosely to disciplines, but need not. They may be either larger or smaller. Thus, the adaptationist perspective, in which the parts of an organism are all analyzed in terms of their evolutionary function — those aspects of behavior responsible for their selection, elaboration, and maintenance is larger than a discipline, unless disciplinary lines are drawn extremely broadly to include it — the discipline of evolutionary biology, for example. So also, fate maps seem plausible as perspectives in this sense, in which the cells of a developing embryo (or layers, or regions — so this is not confined to a level) are marked to indicate what they will become are a specialized representational tool within classical developmental biology, and thus much smaller

67 See F. Lighthall, 'Social Psychological Adaptation: Structures, Agendas, and Problems' (unpublished ms).

than a discipline. There are specialized tools for revealing these (such as radio-isotope labelling, which can give an iconic representation of the fate of a cell, layer, or region through development).

If I were to rename them now (as I probably should), I would call them sections — short for cross sections (or perhaps sometimes transverse sections in messier cases!) — views chosen by architects, engineers, and anatomists to give particularly revealing views of aspects of their complex structures, views which can cross-cut one another in various ways, and at various angles, views which are individually recognized as incomplete, views which may be specialized for or better for representing or for solving different problems, and views which, like perspectives, contain information not only individually, but also in how they articulate.

The important ontological features of perspectives are captured in figure 2d⁶⁸ — and indicates that:

(10) perspectives cannot be ordered compositionally relative to one another — you cannot say that the objects or parts of one perspective are ‘really’ composed of the objects or parts of another — or if you could do so, that a corresponding claim could be made in the other direction with equal justice. (Are anatomical features composed of physiological processes or conversely? The question doesn’t make sense, but information from each perspective is relevant to the solution of at least some problems in the other.) But not all compositional talk is forbidden from perspectives, even putting levels aside as a special case. For a perspective, you may (and usually will, if you are a materialist!) be able to find lower level objects (indeed, a greatest lower bound, or GLB of largest common parts) such that all of the entities in the perspectives are composed of them — *de facto* atoms, as it were. There may also similarly be higher level objects (corre-

68 The terms ‘descriptive complexity’ and ‘interactional complexity’ refer to the complexity of mappings of object boundaries from one perspective to another, and to the strength and structure of causal interactions between variables and parts in different perspectives. They are defined and discussed in detail in my ‘Complexity and Organization.’

spondingly, a lowest upper bound, or LUB of smallest common systems), such that the objects in the perspective are all parts of those objects (e.g., organisms), but for the regions in between the GLBs and LUBs, there is at most local orderability of compositionally ordered parts within each of the perspectives. If they exist, GLBs and LUBs of a set of perspectives are rich in implications. The greatest lower bound and lowest upper bound decompositions of embedded and embedding systems will both be robust, because they will be level-descriptions and will be orderable relative to one another. Given their unambiguous robustness and status as entities at levels, there will be a tendency to regard them as more important or ontologically central descriptions than descriptions derived from the perspectives in between. (Reductionists will tend to favor the GLB descriptions on down, and functionalists or holists will tend to favor the LUB descriptions, and possibly on up. If we accept the objectivity of the GLB and LUB descriptions, this will tend⁶⁹ to fix all of the perspectives between them within the objective realm (or more generally, to give them any ontological properties common to the two bounding levels). If so, these properties will be aggregative rather than emergent properties for that class and within that range of descriptions of systems. (See my 'Forms of Aggregativity' and 'Emergence as non-Aggregativity'.)

The most interesting thing about perspectives follows from this ontological feature:

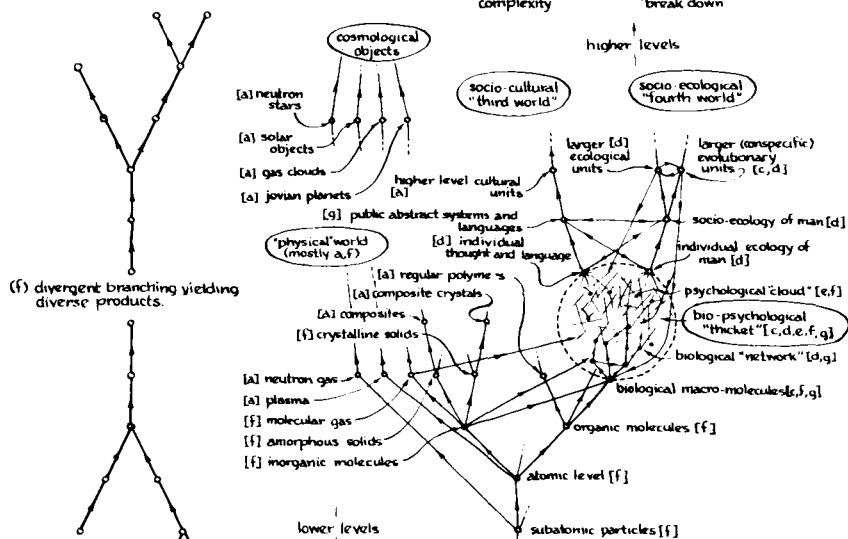
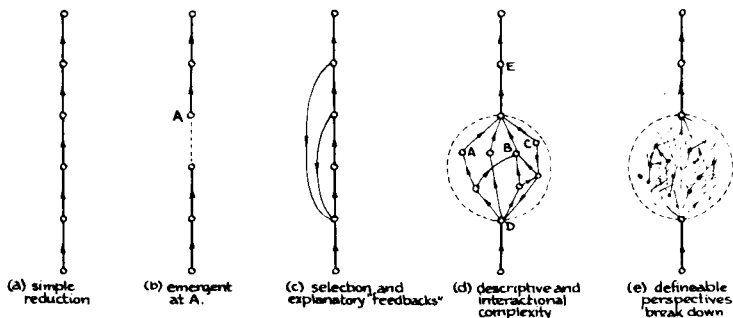
(11) if compositional ordering relations break down as they may between descriptions of the same object in different perspectives, then above a GLB and below an LUB, traditional formulations of materialism are inadequate for ontological reasons because you can't say what

69 The path here is fraught with error and tempting but dangerous inferences. I think that the tendencies are real, but that there are exceptions to everything said in the rest of this paragraph. All of the kinds of qualifications about finding genuinely aggregative properties in nature urged in my 'Emergence as non-Aggregativity' apply here. At present, it is important to regard this claim as a statement about discovery heuristics or as a statement of psychological tendencies. I think that more can be said which is sound, but a lot more careful exploration is required first.

is composed of what, although your complex system contains nothing immaterial. If this is right, then in that interesting size range between atoms and organisms (or perhaps in many regions between atoms and societies) you will often find a situation for parts or properties where neither type-identities nor token-identities appear to be of much use (see my 'Reductionism, Levels of Organization, and the Mind-Body Problem'). Token identities aren't of much use anyway, beyond expressing advocacy of a token materialism. As Nancy Cartwright said in a recent lecture,⁷⁰ token identities are too weak — they ignore the systematic regularities that are there, even in messy cases. The problem (as she also noted) for type identities (and also for laws as they are normally conceived of by philosophers) is that the systematic regularities aren't exceptionless either. And you can't make them exceptionless without introducing so many qualifications as to make them essentially useless. (Compare my 'Reductive Explanation.') But we can't even get to this juncture if we can't specify composition relations, and in this interregnum of multiple partial incomplete perspectives, we can't. This might seem to be the death knell for any possible reductionisms — as it clearly is for any formalist or deductive accounts of reduction. It is also clearly at least highly problematic for any identity-based accounts like that urged in my 'Reductionism, Levels of Organization, and the Mind-Body Problem' and 'Reductive Explanation.' (See also related discussions of what happens when localizations break down in my 'Complexity and Organization,' and, in greater depth — using connectionist models as an example — in Bechtel and Richardson.) But note also that this breakdown occurs without really doing anything to compromise the spirit of materialism because we can understand in materialistic terms why compositional relations are problematic, and a variety of general structural and methodological features about the situation, and can do so without admitting that there are any phenomena (or regularities) that we cannot explain. This is a remarkable situation, but one which charac-

70 Nancy Cartwright, 'Fundamentalism vs. the Patchwork of Laws,' lecture and draft ms, The University of Chicago, 22 October 1993.

Complex Orderings - of levels and perspectives: nodes are levels or perspectives arrows give direction of explanation



(h) A reductionistic (?) illustrative*
phylogenetic ontology of our world as we see it
[letters in parentheses refer to local character of network around that node]

* A diagram like this is obviously highly tentative. Although it has been constructed with many specific relations in mind, I would claim accuracy only of a general qualitative sort - i.e., for the rough general distribution of network properties, as indicated, e.g., by the distribution of letters.

W.C. Wimsatt 1975



Figure 2: Complex Orderings of Levels and Perspectives. This figure depicts some of the modes of composition of aggregate and complex systems, ordered in terms of the direction of explanatory relations, which in simple systems accords with compositional relations, with behavior of the wholes explained in terms of the properties and relations of the parts. Thus the simple reduction picture of the 'unity of science' movement is given by figure 2a, in which each level explains the one above it, a picture which, as Roger Sperry complained, '...seeks to explain eventually everything in terms of essentially nothing' (quoted in my 'Reductionism, Levels of Organization, and the Mind-Body Problem'). The classical picture of emergence (as a failure of reduction) introduces a gap, as in figure 2b. (This account is rejected in favor of an account in which emergence is consistent with reduction in my 'Forms of Aggregativity.') Explanatory feedbacks from higher to lower levels are introduced by selection processes, diagrammed in figure 2c (See D.T. Campbell, 'Downwards Causation in Hierarchically Organized Systems,' in T. Dobzhansky and F. Ayala, eds., *Philosophy of Biology* [San Francisco: University of California Press 1974]). Complex organization of the phenotype (as a product of selection processes) builds on these explanatory feedbacks from higher to lower levels to create further ordering problems with the emergence of perspectives (2d), and increased interactional complexity leading to increased numbers of cross-perspectival problems leads to breakdowns of and ambiguities in the boundaries between perspectives, resulting (2e) in what I have called 'causal thickets' ('Reductionism, Levels of Organization, and the Mind-Body Problem'). Figure 2h is a compound diagram illustrating the composition modes of various kinds of physical, biological, psychological, and social systems. It is intended to be illustrative, in that I will not argue in detail for its architecture, and it is as likely to be wrong in the representation of complex physical systems as it is to be wrong in the biological, psychological, social, and cultural realms. I do not, however, know of obvious errors anywhere. The biological organism (a developed language-using socialized human) has perspectival structure (actually at its lower levels of biological organization), merging continuously with causal thicket structure as we get into the internalized psychological and social realm. The two ontological lineages emerging from this are those of cultural objects (abstract objects, which would presumably also be viewable as abstract relational properties of objects in the second lineage), and socio-ecological objects, which are kinds of complex material systems having the whole range of social, ecological, biological, cultural, and psychological properties. I think in fact that the connectivity patterns relating these various realms inside and outside of the individual are much more complex than represented here (thus social institutions obviously are complex hybrids of objects at a variety of levels from both of these lineages); that there are causal thickets above and outside of the individual interacting rather directly in a variety of ways with causal thickets inside of the individual; and that an embodied socialized theory of consciousness is required.

terizes, for at least some problems and properties, all naturally evolved systems.

(12) Organisms can share dimensions of niches however, in that some causal factors can be causally important to all, or to an important subset of them. This makes these dimensions or causal factors particularly important in explaining their behavior, and also particularly real, objective, robust. One way for perspectives to emerge (in the sense of sections, above) would be around causal clusters of variables which are robust niche dimensions — as sets of descriptive variables whose analysis generates adequate solutions to classes of correlative problems. (The primary qualities would be good examples here, and statics [for physical structures] and anatomy [for biological ones] stand as good correlative ‘perspectival’ theoretical structures. Indeed, insofar as a theory deals with only a subset of the causally relevant properties of an object, it has a perspectival character, but if the properties it deals with are sufficiently robust and fruitful, it may be easy to forget this fact.) It is an interesting question to ask whether and when theories (in general, or in particular: ‘folk psychology’ or Kuhnian paradigms) should be viewed as being or as providing a perspective.

(13) How do we judge whether perspectives are real? I think that there are two ways. First, when there is agreement across perspectives in identifying or saying things about objects they access in common, this judgment not only recognizes the robustness of the object, but — indirectly — confirms the means of access. Secondly, we can treat the perspective as object, rather than as means of access to other objects. But then the same criteria of robustness should apply — the extent to which the perspective is multiply detectable, in this case by being articulatable with other perspectives, affects the degree to which it is real to us. We can do this in a variety of ways, with different ways appropriate to the kind of perspective it is. I will mention only one here, because it is already commonly recognized in methodological discussions in the social sciences. It is this activity we are practicing when we practice *Verstehen* to understand action. The target here is not action, or its justification, but the explanation of the action. And we can provide an explanation by putting ourselves in the other agent’s shoes, and see that the action is rationalizable from their perspective. (It doesn’t justify the action of course — the perspective

could be that of a heinous fellow.) If we understand the action, in the sense of explaining it, then by taking on the perspective, and successfully practicing *Verstehen* (seeing the act in the way the agent did, and judging it to be rational or otherwise explicable from their perspective), we have not only explained the action, but also confirmed the existence of that perspective, and its salience to the action.

IV Causal Thickets

I noted above that each perspective will tend also to contribute to the solution of some problems which it cannot solve by itself — and that for more complex systems, this would tend to happen more frequently. With increases in the complexity of objects, and in their number and variety of degrees of freedom, they can interact with one another in more varied and complex ways, and more problems involving their behavior require the use of two or more perspectives for their solution. Sometimes, when there is a range of problems which can characteristically be solved using two or three particular perspectives or disciplines together, a new sub-discipline gets formed (e.g., psycholinguistics, or even developmental psycholinguistics). Sometimes problems are fought over by practitioners from two or more different perspectives. And sometimes problems appear to be big enough, or generally enough stated (e.g., the ‘mind-body’ problem) that they seem to be intrinsically multi-perspectival. Since a perspective maintains its identity in part by having problems which its corresponding discipline can characteristically solve by itself, the characteristic identification of important problems with certain perspectives, and the identity of perspectives tends to break down simultaneously. When the relative frequency of such problems gets too high (either as a function of the way the world is or as a function of the inefficiency of our conceptualizations in organizing our problem-structures), the boundaries of perspectives begins to break down and it becomes more difficult to decide which perspective (or perspectives) a problem belongs to. (Correspondingly, as the preceding parenthetical remark might suggest, it becomes harder to tell when we are talking about our world and when we are reflecting only or

primarily our own conceptualizations. Thus the 'perspective' and many of the claims of the new deconstructionists and sociological relativists are in a way predictable and explainable in this situation — which I remind you, is still characterizable within a broadly materialistic perspective!

This breakdown of boundaries induces competition among the different methodologies associated with the different perspectives, and so we should expect that methodological disagreements will proliferate, along with disputes about how to fragment systems into parts and how to best define key terms. As the boundaries break down this far, not only is it true that others perspectives intrude on the one you wish to argue for, but also your perspective can seem to reach legitimately to the horizon. Paradoxically, as the perspectives weaken in their own domain, they don't retreat, like good scientific theories, but their generality appears to increase without bound. (Deconstructionism is not the only banner to have claimed the whole field — witness methodological individualism under the banner of rational decision theory (fighting mostly prisoners' dilemmas), or the self-reinforcing behaviorisms of a generation ago. At that point, philosophers may rush in where scientists fear to tread — or perhaps have done so and stubbed their toes! Here if anywhere, philosophers may be useful if they know the lay of the land.

Perspectives have now degenerated into a causal thicket. This term is intended to indicate a situation of disorder and boundary ambiguities. Perspectives may still seem to have an organizing power (just as viewing a thicket or shrub from different sides will reveal a shape to its bushy confusion), but there will be too many boundary disputes. Claims may be made that phenomena are at a given level, or are to be viewed from a given perspective, and any level of analysis or perspective which has successful associated theories will attempt to claim disputed territory. But that is just the point — there will be a lot of disputed territory, and the disputes will often turn on how the system is to be cut up for analysis — or even (to those of a holistic persuasion) whether it can be cut up for analysis at all. (Some connectionists seem to expect that local analysis will fail for all interesting mental properties, which will therefore be holistically distributed, while others are busy denying that we will have to recognize any mental properties

because they don't find them at any locations!) Most complex biological problems involve levels, perspectives, or a combination of both — except in neurophysiology and some areas of developmental biology. The neurophysiological, psychological, and social realms are mostly thickets, which are only occasionally well-ordered enough for local problems to be treated as perspectival or level-relative problems. All of this enormously complicates talk of reduction, because with such multiply connected entities, and the failure of the ability to say what is composed of what, it may now be almost impossible to determine what is being reduced, what is doing the reducing, and what even is the proper scope of the system under analysis and the problem we are being asked to solve.

The proliferation of disputes of this form involves an unusually large proportion of conceptual issues, methodological arguments and boundary disputes. This phenomenon is predictable simply from looking at the form of complexity such systems take, and the form disputes should take when boundaries break down. Some of these disputes are likely to indicate sources of genuine disagreement, but this can't be determined when so many things are up for grabs. Moreover, the natural tendencies of most theorists towards expansionist territorial claims, and of all of us to understand the merits of our own positions better than those of our opponents makes frequent disagreements seem inevitable where there are boundary ambiguities. Localization of problems with the existing conceptual structures, and of disputes to the right trouble spots will have to await the development of conceptual structures, methodologies, and new explanations of mechanisms in terms of them. If this explanation for their occurrence is correct or nearly so, an unusually large fraction of the disputes should be resolvable as people from the different groups learn and work out how to talk with one another, if (and it is a big sociological if) they maintain a commitment to try to understand one another rather than bloating their reputations by taking cheap shots at the opposition. This is perhaps the deepest pragmatic commitment of science — that it is in one's interest to come to understand differences, and then to resolve them. This yields an ultimately realist picture only because the world has an indefinitely large number of constraints for acceptable theories, if you know where to look. But

you'd better get an overall sense of the geography before you decide on your colonizing strategy. But this has a lesson as well, of which eliminativists should beware: you don't make friends with the natives (folk) by denying their legitimacy (psychology), and you can't tell what's in the territory without a native guide. You can play imperialist without heeding these warnings, but it usually requires more resources, costs a lot more, and takes a lot longer. And you may end up having to grant them autonomy anyway!

So far, we seem to have defined causal thickets as a kind of wastebasket category. They needn't be. On a priori grounds, considering the possible connectivities of causal networks, shouldn't causal thickets be the norm, and relatively insulated levels or perspectives the rare cases? Wouldn't causal thickets be, as it were, the high entropy or generic states of the causal structure of the universe — sort of an ontological primal slime? This is to exchange assumptions of simplicity and order in the universe for assumptions of randomness in causal connection — a kind of structural disorder. An absurd view, one might say, but not a priori absurd. To be sure, we wouldn't exist, and couldn't survive in such a universe, but considering it provides a useful kind of change in perspective. One of the remarkable things about our universe is the degree of order we find in it. To be sure, it is not an exceptionless static order — crystalline without flaw. There are regularities at all levels, and mechanisms tying them together, and perspectives which give cross-sectional cuts on the phenomena for a range of problems. And then there are some things which are just too multiply connected to fit exhaustively into any of these ontological categories. And we can say something about the conditions in which we expect each of these to arise, and their methodological consequences. This looks a lot more complex than the old story, but it provides tools and ways of thinking and talking which seem a lot closer to the truth. And, as I've been trying to tell you, that's the way the world is.